VOL. II

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A HANDBOOK

OF THE

PETROLEUM INDUSTRY

BY

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Page			
635, line 7	*for* second *read* minute		
656, formula, "F = etc."	*Insert letter* t *as denominator*		
693, last line of table	*for* 17 O.D. *read* 18 O.D.		
699–711.	*Formulæ (A) and (B) have been reversed; i.e., the one here designated (A) should be (B), and vice versa. When correctly designated, (A) is for values of P less than 581 pounds per square inch, or for values of* $\frac{t}{D}$ *less than 0.023, while (B) is for values greater than these. Formula (A), as used here, is Formula (G) in Stewart's original paper. These formulæ were correctly used in calculating the tables, pages 700–711.*		
699.	*First sentence under Formula (B) should read,* "Formula (A) is for values of P less than 581 pounds or for values of $\frac{t}{D}$ less than 0.023, etc."		
706, column headed "8.000"	*for* 4706 *read* 3706		
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717, line immediately above table	" 16 " 716		
719.	*The simplification of Birnie's formula (10) should read* $P = \frac{10(D_1^2 - D_2^2)}{13D_1^2 + 7D_2^2} f;$		
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		" 17 O.D.	" 18 O.D.
		" 19 O.D.	" 20 O.D.
724, column headed "Factor of safety = 10," line 23		" 240	" 340
746, line 4		" 0.10	" 0.04
746, " 5		" 0.06	" 0.05
746, " 5		" 50,000 pounds	" 45,000 pounds
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Index—Disregard page references to chapter on "Pipe Standards and Use of Pipe," until corrected in reprinting.

REFINING

BY

A. D. SMITH

INTRODUCTION

THE subject of petroleum refining embraces in its broadest sense the technology of petroleum from its production at the wells to its ultimate distribution into the multitude of diversified products refined and manufactured therefrom. In more limited scope, it considers methods and apparatus for the separation of crude oil or its intermediates into certain well-defined trade commodities, after the raw product has been delivered by tank car, oil barge, or pipe-line, to the storage tanks of the refinery proper. The present chapter treats of petroleum refining in the more limited sense.

The subject of refining may be divided for systematic presentation into the two general topics of refinery engineering and refinery operation. The first deals with the problems incident to design and construction of plant and refining apparatus, while the second pertains to those of processing and management. The chapter is divided into sub-topics as follows:

PETROLEUM REFINING

Refinery Engineering	*Refinery Operation*
I. Selection of plant site.	I. General management.
II. General plant design.	II. General refining processes.
III. Standard apparatus design.	III. Special refining processes.
IV. Special apparatus design.	IV. Fire prevention.
V. General construction and equipment.	V. Yields and costs.
VI. Fire-fighting equipment.	

REFINERY ENGINEERING

I. SELECTION OF SITE

The immediate factors that should govern the choice of a refinery site are, in the order of their importance; crude supply, with definite understanding beforehand; as to quantity and delivered cost; availability of unfailing water for condensing and boiler-feed purposes; facilities for rail or water shipments; a reasonably good ground topography from the standpoint of erection and drainage; and desirable adjacent markets or equitable freight rates to competitive points.

Other important considerations that should influence selection are: the nature of the water supply, whether hard or soft, and if hard, whether amenable to satisfactory treatment for boiler-feed purposes; whether drainage effluent may later form the basis

of a pollution suit, whether the location is above all remote possibility of river flood or spring tide; and whether the region is generally free from severe electrical disturbances, high winds, or tropical storms. Such economic features as proximity to cheap natural gas or coal for fuel purposes or nearness to markets for refinery chemicals (litharge, sulphuric acid, caustic soda, soda ash, etc.), all have their bearing. Lastly, the hygienic and social conditions in the immediate vicinity should be given more than a passing thought, as aside from any humanitarian reason, an adverse selection will mean a constant labor turnover with resultant inefficiency in plant operation. Small skimming plants operating under frenzied conditions of demand have often been temporarily successful while disregarding many of the requirements noted above; but an adherence to a majority of the points mentioned is essential to the permanent success of any large or moderately large refinery.

Where a general geographical location has been decided upon for business reasons, as, for example, when the plant is to be located near a congested industrial district on account of close markets, the refinery engineer has no light problem. Various restrictions as to approach of railroad spurs, city ordinances, fire department regulations, interferences to entering pipe-line, smoke-nuisance laws, etc., etc., loom up at every turn in such localities. Land is ordinarily available only in limited acreage, at almost prohibitive cost, and frequently does not possess the most desirable topography. In addition, adequate capital for extra construction costs incident to such a site is often, and it might be truthfully said is usually, not immediately obtainable; so that the selection of a plant site in any congested territory should be made only after exhaustive engineering study, legal advice and general business counsel.

Again, in selecting a site whose general geographical location has been decided upon in a region remote from supplies and labor market, the engineer is confronted by a different set of problems, requiring for example, the most expert knowledge of river currents, legend of shore line, bearing power of soil, etc., etc. Further, as must be obvious, in addition to general requirements, modifying causes have important bearing on any selection. Thus, considerations of the future should be given serious thought before definitely deciding upon any specific location, even though the immediate engineering problems are of ready solution. A series of hypothetical questions should be proposed and answered according to the judgment of the engineer, and the situation should be studied from every angle before a final decision is reached. While each selection is a problem in itself, the following generalities are in order, assuming that the production intended for the plant is owned or controlled by the prospective interests about to engage in the refining business. Does the acreage held consist of sufficiently proven territory to warrant the assumption of a future crude supply adequate to justify the expense of investment? Has the life of wells in a similar field or from the same depth of sand been given proper consideration as applying to future supply? Is there strong competition for crude, and is other acreage in nearby territory under development? Has there been more than one grade of crude produced in the area under consideration, and if so was the difference in quality such as to require decidedly different refining equipment?

If purchasing the crude from outside sources is contemplated, the same information as to geological data, logs of wells, etc., is desirable from any standpoint. But the question of the responsibility of the company which is to supply the crude, and particularly of its reputation for living up to contracts and disposition to renew, is all important. Among the important hypothetical questions are the following: What are the future probabilities of failure in condensing water source? Is a shift in river course or coast line likely to occur? What effect will a possible revision of freight rates have on competitive points; or (if on navigable water) what will be the corresponding effect on barge or steamer delivery? The list might be continued, but the above will serve the purpose

of illustrating future considerations and will demonstrate the advisability of not choosing a site in haste.

As a further aid in selection, the following suggestions are offered, they being in every case apparently minor details whose neglect has cost from hundreds to thousands of dollars to various refineries at one location or another. First, in the matter of any proposed agreement as to any railroad spur connection, laying of storage, rip or loading tracks, crossovers, etc., there should be a complete written agreement with the railroad in question, as to feasibility of approach. If any change of rate or base is discussed as an inducement for location, such a tentative agreement should likewise be made a matter of written record before concluding an option. Such a course is no reflection on the railroads, as an opinion or proposal made in good faith by a partially informed agent may be physically impossible of accomplishment when all the data are reviewed by the engineering department. Furthermore, the legal counsel of the road may find some obstacle in law or interstate commerce regulation preventing the granting of a new rate, however favorable the road itself may be to that course. When it is considered how an adverse decision, rendered after a site has been purchased, might depreciate the prospective earning power of the new industry, the purpose of this warning becomes at once apparent.

In locating on a navigable river or harbor front, it is an easy matter to ascertain from the nearest U. S. District Engineer's office whether the proposed site is above the recorded level of tidal wave or flood. In an inland country where such information is unobtainable, the study of topographical data may well help a great deal, and in its absence repeated questioning of the "oldest inhabitant" often brings out the information that at some time or other the site under consideration was under several feet of water. In general, in our southwestern country, or in any locality of shallow rivers and slight drainage, distrust a low valley site, particularly one near a tortuous, sluggishly flowing stream. In fact, careful search will almost invariably disclose a record of past high water in the shape of drift lodged in trees or fence wire. No matter what other advantages are offered, never select a site when there is reason to believe that it has ever been under water because of flood or tide. The occurrence will repeat itself, and the operating danger with such a menace at hand is too great to offset any gain.

It has already been intimated that the question of water supply for condensing and boiler-feed purposes is all important.

Before definitely selecting any site, determine by actual test the character, average temperature and quantity of water available. This, a simple problem on a large navigable river, lake, ocean or harbor site, is more complex in inland districts. Often an excellent flow of cold, clear water of moderate hardness is found as an underground current adjacent to a river bed, when the river is itself dry, or beneath the floor of a valley. Such water is often encountered at a depth varying from 25 to 50 feet, and a simple drive point will test out such a source at small expense. At depths varying from 800 to 1200 feet, artesian water in heavy flow is often procurable in territory adjacent to the foothills of low mountain ranges. In short, it seems hardly necessary to state that any company contemplating a refinery, whether it be a small 1500-barrel skimming plant representing an investment of $75,000, or a plant costing $2,000,000, or more, can afford to spend from a few hundred to several thousand dollars if necessary, to determine beyond a doubt that it has a dependable water supply. Of course, a limited supply has been made to answer, through the agency of cooling towers, spray ponds, rain ponds, etc., so common in the southwest, but such water shortly becomes heavily saturated with salts, and is highly objectionable for boiler-feed purposes and inefficient for condensing purposes. It is scarcely possible to lay too much emphasis on an adequate water supply. Reject a site that does not possess it.

A waste channel discharging into some large harbor or river not used as a so-called public water-supply source is free from many annoyances, but sites possessing this advantage are comparatively rare. Where an inland stream is used never trust appearances, but determine positively that it is not classed as a public water-supply source. It may have long since passed out of general use as such, an analysis may show its solids ten times greater than the maximum recommended for a potable water, but before waste is discharged into it, be sure of its legal status. Furthermore, avoid if possible, discharging waste into any stream whose status is not a matter of record, for there is always the chance of a suit for pollution. If it can be shown, for instance, that cattle drank from the stream, no matter if the analysis of a sample taken above point of contamination shows the water as absolutely unfit for man or beast, the court's view in such cases is usually that though the water may not be an ideal potable water it was nevertheless used as such, and that the plaintiff is entitled to damages. Hence the necessity of investigating the site problem from this angle and of avoiding future damage suits.

As to the selection of a site from the point of view of the soil itself, a sandy clay loam is the most desirable. An all-clay soil mires heavily in rainy weather, and is difficult to dig for drainage ditches, pipe-lines, etc., while an all-sand soil is unstable, poor for foundations and makes leaks difficult to detect. Where it is a question of choice between the two, preference should be given to the clay soil without hesitation, but, as stated, the ideal ground is of sandy clay loam, not miring readily, giving secure foundation at moderate depth and at the same time being easily ditched for drainage or other purposes. Where on account of the general geographical location, it is necessary to select a site with a soil of low bearing power, such as the Mississippi river bottom land, the engineer has little choice. He must be guided by local engineering precedent and government reports, supplemented by test data of his own taking, but he may assume generally without test a slightly higher bearing power for land that has been cleared for some years, than for virgin swamp. The converse of this problem, i.e., a site on soil with outcropping rock close to the surface, is sometimes met by the engineer and offers its special problems, but is sufficiently rare to deserve only parting comment.

One other feature which may be lightly touched upon is the necessity of avoiding a location where electrical disturbances are prevalent. Where a general geographical location has already been decided upon and the region is known for its electric storms, it is a difficult problem indeed to select an individual location even moderately free from this menace. It is a curious and inexplicable fact, however, that certain areas seem to be centers of electrical disturbances, while adjacent areas only a few miles away are rarely visited with storms of severe intensity. Information that can serve as a guide in selection is often obtainable from local sources, but familiarity with the country is the best guide in a problem of this nature.

Other specific points affecting selection might be discussed at length but can best be treated in connection with the topics following. From a general standpoint, it may be added that the problem of a wise choice in the selection of a site revolves about the ability of the engineer to give proper proportionate values to all the factors entering into the question. Familiarity with the proposed design of the plant and the process it is to employ, as well as its general contemplated business policy, are all important considerations, indirectly affecting the site problem. In short, the greater the amount of information with which the latter is approached the more satisfactory will be its solution.

II. GENERAL PLANT DESIGN

The factors controlling the design of a refinery are numerous and varied, each modifying and supplementing the other, so that it is not only a practical impossibility, but undesirable from an engineering standpoint to consider any one factor without at the

same time noting its effect on others. For convenience in discussion, the various factors may be grouped under appropriate headings as in the following table:

(1) Capital available.
(2) Size of site and dimensions.
(3) Contour of site and nature of soil.
(4) Railroad connections.
(5) Abutting property.
(6) Quantity of water available.
(7) Quantity and grade of crude.
(8) Nature of crude delivery.
(9) General refining scheme.
(10) Special refining units.
(11) Storage.
(12) Buildings.
(13) General.

Capital available.—The amount of capital available for construction of a refinery will control the design in several ways, depending upon (*a*) whether the entire fund to be subscribed is available immediately or in deferred installments; (*b*) whether it is the intention to build a plant of definite capacity with really adequate storage, or whether the plan of erection contemplates a refinery that will handle the maximum amount of crude possible with the money at command, with a minimum of storage and generally inferior construction.

Adequate capital immediately available for material as purchased, even though the total amount subscribed be less than good engineering practice would demand, makes possible a far better type of design and construction than can be obtained if money is supplied at irregular intervals, as, for example, from the sale of stock or bonds. As a corollary to this statement, it follows that where a definite sum is set aside to build a plant with the understanding that a certain fixed quantity of crude will be refined (plan *b*), the engineer can usually secure far more advantageous construction contracts, obtain better deliveries of material, and plan for greater efficiency both in immediate construction and for future operation. Such a plan of erection presupposes complete knowledge of the process to be used and the nature of the crude, as well as the extent and degree of refining contemplated. In short it includes the necessary technical information concerning the number and design of stills, agitators, tanks, etc., that are required to refine a certain amount of crude daily.

It is obvious from the above that even before the question of cost of site, or special engineering requirements, such as wharfage, piling, etc., enters into the problem, it is absolutely impossible to give a hard-and-fast rule for computing the exact cost of refinery construction in dollars per barrel of crude to be refined daily. However, such a figure, even if approximate, would be of decided benefit in roughly checking a preliminary estimate, and for such purposes the appended figures are furnished. In this connection exception as to approximation might be made in the case of the typical Pennsylvania refinery, manufacturing only high-grade products, where refining methods are practically standard. Thus with cost on present investment showing from $240 to $1000 per barrel of crude refined for a score of Pennsylvania refineries, the average cost amounted to $725 per barrel per rated daily capacity. Assuming the depreciation in equipment about equal to the advance in materials and labor, the above value closely checks the computed cost of to-day for similar refining equipment, which, it may be said in passing, is still about 80 to 100 per cent above pre-war costs.

On account of their simplicity of construction, the cost of skimming plants may also be readily reduced to the barrel basis. Such plants have been built as low as $35 per barrel

of refining capacity, with an average cost of about \$200 to \$225 per barrel, where new material was used throughout, and to-day could be erected at an investment of \$250 to \$400 per barrel of daily refining capacity. However, as stated previously, unless some idea is given of the storage capacity of the type of plant under discussion, the minimum figures given as construction costs may represent the merest shell of a refinery, capable, it is true, of running as much crude as one costing 50 per cent more per barrel, but unable to store its refined products for more than a small fractional period of its running capacity. In view of all these facts the values in the following table should never be considered absolute, but should be closely checked by actual estimate before any definite line of action is decided on.

REFINERY CONSTRUCTION COSTS

(Per barrel of daily rated capacity)

(*a*) Pennsylvania, complete with lubricating plant	\$400–\$900
(*b*) Lima, O., complete with lubricating plant	700–1200
(*c*) Mid-continent, skimming plant	250– 400
(*d*) Mid-continent, complete with lubricating plant	600–1100
(*e*) Texas, complete with lubricating plant	500–1000
(*f*) Mexico or California, skimming plant	350– 500
(*g*) California, complete with plant for lubricants	500–1000

Size of site and dimensions.—While the size of the site should be proportioned to the amount of crude to be refined, with due allowance for storage and future expansion, there is again no fixed rule in this matter. Plants range all the way from 10 barrels to 100 barrels refining capacity per acre of land owned. It is a general rule to secure a site, especially where land is cheap, far in excess of the actual present requirements. Frequently the owner will not sell except in entirety so that in order to secure a desirable site it is sometimes necessary to purchase from two to five times the acreage actually necessary. Thus, in the lower Mississippi district, to secure adequate river frontage and drainage rights, an acreage comprising 60 per cent of virgin swamp often has to be bought. As a converse to these conditions, there is the site near some congested center of industry where distances between tanks, agitators, etc., must be reduced to a low minimum with special fire protection introduced as an offset to this disadvantage. While in the first instance the general design of plant is but little affected except as the investment for land cuts down funds available otherwise, in the second case highly specialized construction is necessary, thus materially affecting the design and cost of the plant.

Again while a certain actual acreage may be present in the site, it may be in a long parallelogram or of irregular shape, thus modifying the design to a considerable degree. The illustration, Fig. 1, gives an instance of irregular shaped parcels of land surveyed under the old French arpent system in the river district of Louisiana, above the city of New Orleans. While, as stated, the size of a refinery site is an individual problem in itself, dependent on location, nature of process to be employed and amount of storage proposed in connection with a definite quantity of crude to be daily refined, it is generally customary, where it is possible to purchase land within a reasonable figure, to allow about 100 to 150 acres of land for every 5000 barrels of rated capacity, and about half of this acreage where land is excessive in cost. Very efficient refineries have been built on far less acreage. There exist in Pennsylvania to-day plants with capacities from 500 to 1000 barrels per day built on 5 to 20 acres of land, but of course the fire risk is heavy and the lack of any great quantity of storage is self-evident.

Contour of site and nature of soil.—Where a site of reasonably good topography has been selected and at the same time is well drained, the engineering problems to be met

in the refinery design are negligible as far as the site itself is concerned. Where for commercial and geographical reasons a site of uneven contour or soil of low-bearing power has been selected before an attempt is made to design the plant, a contour map should

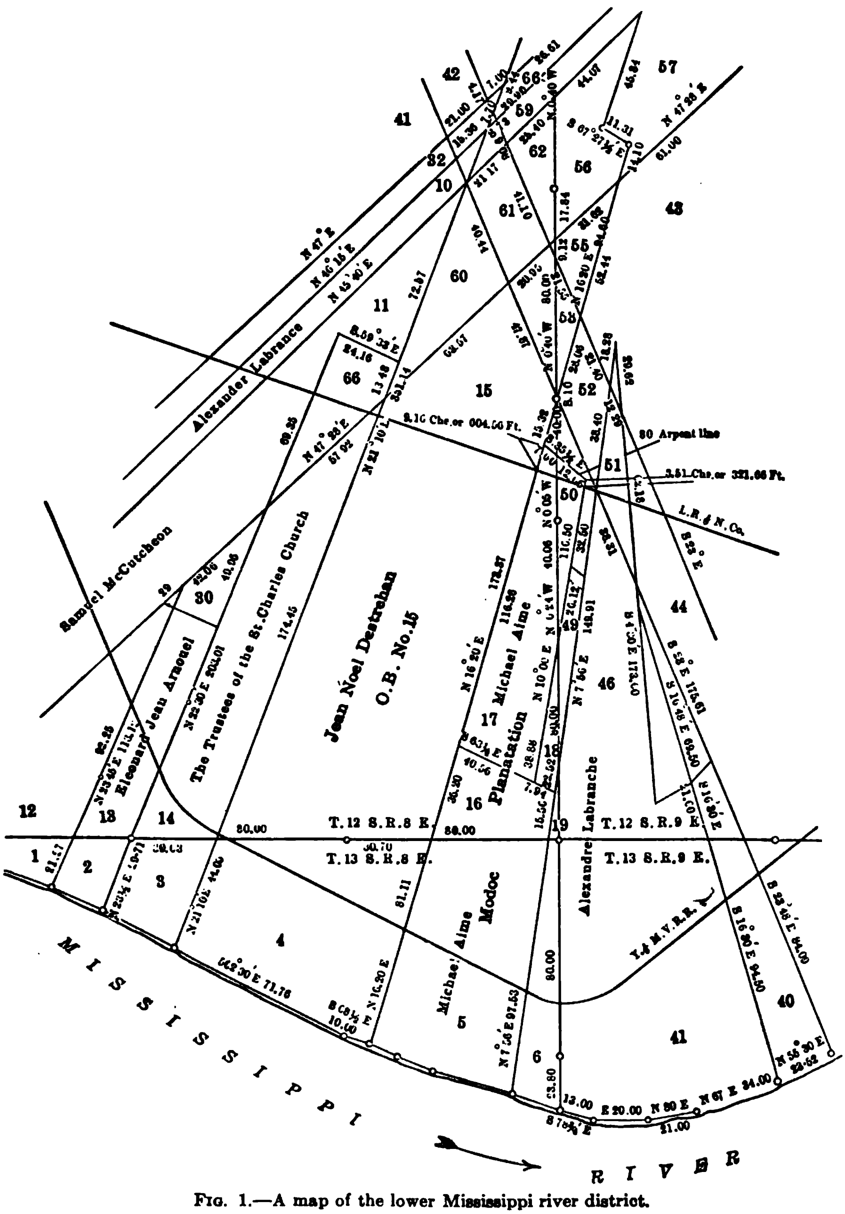


FIG. 1.—A map of the lower Mississippi river district.

be prepared, particularly if the plot exceeds 25 acres or more in extent. The author in a previously published article [1] suggests that a map be laid out conveniently in squares of

[1] National Petroleum News, Sept. 8, 1920.

50, 100 or 200-foot side on a corresponding scale to the inch. The scale taken depends on the general nature of the ground and extent of the construction contemplated. Levels should be taken at every 50, 100, 200 or 500 feet, depending again on natural contours and structures proposed. The expense incident to such work is repaid many fold in the construction following. For example, consider a site adjacent to an inland river liable to sudden rises of great volume so typical of rivers in the southwest. Along rivers

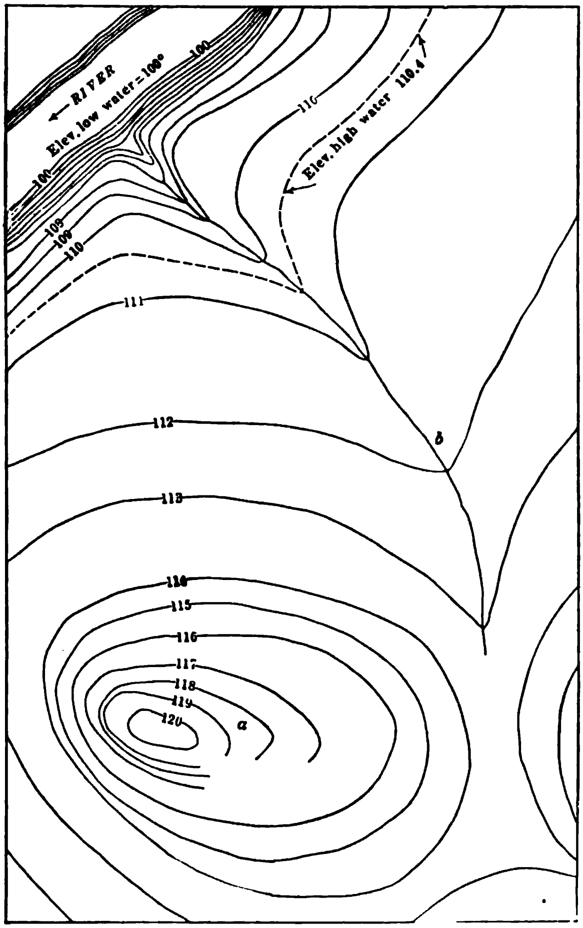


FIG. 2.—Contour map of a refinery site.

of this type the land immediately adjacent to the river bed is often higher by 5 or 10 feet than the land half a mile or so inland, and in the course of another half mile or so slopes gradually upward from the low level to an elevation equaling that adjacent to the river, the change in levels being so gradual that the eye is invariably deceived. Failure to take levels in such a case often results in locating a part or the whole of a plant in comparatively low land, thus giving rise to a series of troubles, of which the least is an increased cost of drains and sewers and the worst a very good chance of providing an easy passage for a sea of backwater at flood stage. A location half a mile further inland would mean

an elevation 15 to 20 feet higher, out of all possible danger from high water. In fact, there is no plant so small that one can afford to build it without engineering supervision, and none so large but that its engineering corps can spend considerable time in getting exact information on the following: (1) river stages or tides, according to the location of the plant; (2) the amount of sand or mud deposited, important both from flood considerations and navigability of stream; (3) the general character of the ground, whether deep foundations or piling will be necessary to secure stability of structures; (4) the nature of the soil itself, whether corrosive to pipe or plate; and lastly (5) the character of the prevailing atmosphere, whether generally dry or humid, whether free from acid traces or otherwise. All the above are noted with a view to selection of the best protective coverings or pigments for the iron exposed. If a river site or ocean harbor is in question, careful search should be made for records of maximum high water, and these data carefully compared and considered in locating the various units. If it is found that there is the remotest chance of high water flooding even a part of the site, the boiler and power plants should at least be at an elevation above the highest possible water stage.

The contour map illustrated in Fig. 2 will give an idea of the natural physical obstacles to be overcome in the average typical location, and its inspection will at once determine the course of the waste run (*b*) to the river (*r*), and further suggest the high ground at (*a*) as suitable in a general way for the location of stills, boiler plant, etc., subject to modifying factors about to be discussed. It should always be borne in mind, however, that the construction of a large plant will warrant the expenditure of considerable sums for leveling off, filling in, etc., that would not be permissible in a small plant. All this must be duly considered in preparing a layout. The successful designer steers a middle course between excessive foundation costs, desirable alignments, and general arrangement with real refining efficiency as the keynote both from a present and future standpoint.

Railroad connections.—With such a contour map as illustrated at hand and the more general location of stills, boilers, tanks, etc., planned with due respect to drainage, general nature of ground, etc., the line of connecting railroad spur or spurs must first of all be determined before assigning definite locations for the different units. A railroad follows certain undeviating customs which may interfere considerably with the originally planned layout. It is all very well for a commercial agent to advise proceeding with construction because a connecting spur would be promptly installed, etc.; but absolutely nothing should be done until a conference is held with a representative of the engineering department of the road, who will quickly say what approach is feasible. In a plant of large size, where almost the first construction involves a material track or tracks, such a caution is unnecessary. With a small plant or one of moderate size, the case is different and unless the designer is a thoroughly competent engineer or familiar with railroad practice, it is entirely possible that, after building has actually started, the railroad will *not* lay its spur in a direction desired by the builder —and for the best of reasons, safety in operation. A consultation beforehand will avoid many a later misunderstanding. Thus it is not generally known, that on a fast main line double track a spur is invariably connected so that the prevailing traffic will be past the switch points, rather than approaching them, i.e., " trailing points," as shown in Fig. 3.

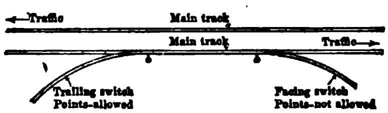
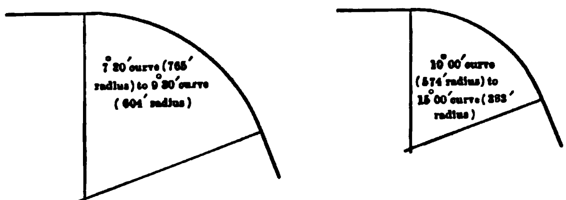


FIG. 3.—Main line turn-outs.

With the limited land at disposal in many refinery sites, it is obvious that the direction of approach is an important factor. Now consider that a curve is contemplated close to the connecting spur, that a creek or run intervenes and the problem becomes even more complicated; here the railroad engineer's advice is essential. The question of a curve is often too lightly considered, for while a curve of even 15° is theoretically allow-

able and even permissible in certain work, it is altogether too sharp for switching tank cars, which, especially when partly loaded, are somewhat unstable on a sharp curve whose outer rail is laid according to usual practice, due to the flow of contents to the low side. The illustration in Fig. 4 shows such a maximum degree curve, to be avoided wherever possible. It also shows a curve of sufficiently generous radius to offer no ground for criticism and at the same time sharp enough to be usable in most locations where a curve must be installed. An extra force is required to push cars around any form of curve, and where occasional "spotting" has to be done by manual labor its disadvantages will be very apparent. Hence at least avoid any curve in the layout near a loading rack or barrel-house platform.

Abutting property.—It is highly desirable to secure a site sufficiently large and removed from a congested district, so that there will be little likelihood of complaint from odor or damage to abutting property from fire. Plants located near the great industrial centers will always have to contend with these problems. While no general rule can be given, it is advisable to locate stills, and particularly pressure stills, on a line at least 100, and better 300, feet from residential property or factory buildings. It is also inadvisable to locate tanks intended for crude, gasoline, benzine or other low-flash products adjacent to such property. It is far better to save such a location for heavy fuel or lubricating storage and thereby reduce fire insurance to the minimum. It also



Curves of reasonable degree to be used in refinery track layouts where possible.

Curves of maximum degree to be avoided in refinery track layouts where possible.

Fig. 4.—Allowable curves for railroad tracts in refinery.

seems hardly necessary to suggest that such a unit as a grease plant or an acid restoring plant, should be located as far from abutting property and from the refinery office as is possible within good engineering limits. The reasons are obvious. Another frequent source of complaint is the smoke from a clay revivifying system, and in designing a plant this unit should be located so as not to be objectionable. If the plant operates a compression system for extracting gasoline from still gases, it is also advisable to have this more or less removed from adjacent property, as it constitutes a risk somewhat similar to stills, or tanks containing low-flash products.

However, when the area is so limited that space must be economized, and tankage or stills erected close to adjacent property, extra care should be exercised in construction with special reference to fire prevention and extinguishing systems, not only from the additional risk to adjacent property, but from a consideration of the more congested condition in the refinery itself. The design should consider special furnace construction and burners to minimize the smoke produced, scrubbing towers for acid vapors and the like, to prevent suits in the nature of smoke nuisance; objectionable, foul and deleterious odors, etc. In many cases the extra cost will be paid by more efficient combustion on the one hand, and by greater recovery of acid on the other. These and similar points are well worth investigating in a design, which is not affected by the nature of the abutting property.

Quantity of water available.—The design of a plant is greatly affected by the amount and nature of its water supply. Next to quantity and quality of crude to be refined it is

perhaps the most important factor in design. An efficiently operated refinery is an impossibility without adequate water. Where the water supply is taken from a lake or clear river of large size, as, for example, in the plants located on the great lakes, the water-supply problem is a very simple one, it being merely necessary to plan an adequate suction line with proper-sized pumps to handle the volume of water desired. The quantity obtainable is limited only by the size of the pumping equipment.

Similarly, plants located on rivers of the Mississippi type can readily obtain ample boiler-feed water by pumping direct from the river and allowing filtration through a simple gravel bed, but wells must be drilled to obtain condensing water of required coolness. However, even in this case it is merely a question of drilling sufficient wells so that again the general design of the plant need scarcely be modified. On the other hand, in inland sites where a limited quantity of water is available, especial provisions have to be exercised, such as the employment of condensing sections of high interchange efficiency, spray ponds, cooling towers and the like, to say nothing of rain ponds and similar means of conserving all the water produced. Different refining equipments require different amounts of water, as will be discussed in special refining apparatus, but as a general proposition, a plant refining all products including lubricants, will require about 1000 to 2000 gallons per minute, per thousand barrels of crude refined daily. Variation in quantity depends on the temperature, the design of condensing coils, and future utilization and recovery of water. With these figures in mind, a thorough survey of the plant site should be made before closing a purchase option, or beginning actual construction, especially if the plant be of several thousand barrels or more projected capacity.

When tapping an underground stream of water either by a deep artesian well or by simple casing if the flow be at a slight depth below surface, the direction of the water course should be established as thoroughly as possible. The location of more than two or three wells in the direction of flow, except in instances of an exceptionally large underground current, does not secure a supply of water proportionate to the investment. In other words, additional wells should be located on a line at right angles to the direction of the flow to the limits of a diminishing supply. The distance between such wells depends upon the local conditions as well as the nature of casing, screen, etc. Most waters permit ordinary wrought pipe; others require galvanized iron or brass screen, depending on the nature of the minerals or gases contained. If the water supply is obtained in coarse gravel, a simple perforated casing suffices. More frequently the presence of sand requires a patented slotted design, or combination of screens and where quicksand is present the problem is often difficult of solution, requiring the services of an expert well-driller, familiar with the locality in question.

In general it is well to avoid a site where the water is known to be of a corrosive nature or loaded with mineral salts or is produced in a stratum of fine quicksand. But where other considerations make a certain location particularly desirable, these objectionable features if not too pronounced may sometimes be overcome at a certain increased refining cost. The feasibility of such treatment and its cost should of course be definitely known as affecting the present and future design of the plant. The rough location of the wells for present need as well as for future development, should likewise be considered as to influence on the location of stills, building, tankage, etc., with due consideration of the previous remarks in this chapter. When possible, all wells should be removed from any danger of fire to the pumping equipment, or from flooding from oil or waste discharge.

Quantity and grade of crude, general refining scheme.—With the questions of site, railroad connections, water supply, etc., satisfactorily solved, the vastly more important problem of plant design as affected by quantity and quality of crude supply demands attention. In conjunction with the closely interrelated general scheme of refining, it involves by far the greatest expenditure of capital, and will therefore be discussed in considerable detail. With the quantity of crude available as the fundamental basis for

computation, the principal modifying causes affecting design under the above classification may be tabulated as follows:

General Refining Scheme

1. Grades of crude oil.
   (*a*) Physical characteristics.
   (*b*) General composition.
   (*c*) Chemical impurities.
2. Basic process employed.
   (*a*) Skimming or topping.
   (*b*) Reduction to coke, paraffin wax and paraffin oils.
   (*c*) Reduction to asphalt flux, paraffin wax and red oils.
   (*d*) Reduction to steam refined, filtered stocks and petrolatum.
   (*e*) Reduction to steam refined, filtered stocks, paraffin wax and neutrals.
   (*f*) Reduction to bright filtered stocks, paraffin wax and neutrals.
   (*g*) Various combinations of the above schemes.
3. Auxiliary processes employed.
   (*a*) Blending.
   (*b*) Compounding.
   (*c*) Grease making.
   (*d*) Candle making.
4. Shipping plan.
   (*a*) Tank cars.
   (*b*) Drums and barrels.
   (*c*) Cans and cases.
   (*d*) Slabs and cakes.

Grades of crude oil.—The physical characteristics and general composition of a crude oil determine to a considerable extent the process that may be used. This in turn governs the design and selection of equipment. Thus it would be folly to consider a simple skimming plant for operation on a high-priced, stock-producing crude, such as the average Pennsylvania grade. Equally absurd would be the selection of stills suitable for the continuous skimming of Mid-Continent crude, for reduction of the heavy water-saturated Panuco Mexican grade. Again, a high sulphur-bearing crude such as South Lima or Indiana can only be refined by the aid of special equipment, involving additional agitator and still capacity over that required for a so-called "sweet" crude of similar yield and physical constants. In short for plant design of the highest efficiency, each crude presents a special problem, and no plant however small should be designed without a complete analysis of the crude at hand as a guide, unless it is produced from an area of comparative uniformity, for example the average Pennsylvania grade. The larger the contemplated plant, the greater the time that should be given to preliminary analytical work, and to the yields of various products and their characteristics as affecting the design or equipment. These facts should be carefully studied from data obtained not from the small pot still, run off in five to six hours, but from a two- or three-barrel still run for the full period estimated for the operating units.

Where this course is impossible, the appended classification of crudes will serve as a rough guide to variations in refining practice and design, peculiar to the grade of crude, apart from the basic refining scheme given above. The reader is cautioned, however, that such a classification is very elastic, and that certain minor differences in design noted in certain plants running on different crudes are the result of custom and routine, characteristic of a certain locality rather than of actual need.

Classification of Crudes Requiring Essential Differences in Plant Design

(a) Mid-Continent (Kentucky, Illinois, Kansas, Oklahoma, etc.).
(b) Pennsylvania (W. Virginia, E. Ohio, etc.).
(c) Lima (North and South Indiana, etc.).
(d) Texas (Gulf Coast, etc.).
(e) California (Mexican, etc.).
(f) Mexican (Heavy California, etc.).
(g) Sumatra (Borneo, Java, Japanese, etc.).
(h) Russian.
(i) Rumanian.

In general, crudes of the Mid-Continent type are of paraffin-asphaltic base and yield distillates that are readily sweetened and produce excellent lubricating oils. In some, the asphalt content predominates to such an extent that after removal of the lighter fractions, the residuum can only be economically sold as fuel oil, or at best reduced and blown to asphalt. Such plants are perfectly justifiable as skimming or stripping units, and require little knowledge of petroleum technology in design. The greater production of Mid-Continent crude is far more suitable, however, for reduction to paraffin wax, neutrals, and red oils, or wax, paraffin oils and coke; while in not a few instances crudes have been produced, notably in the Billings and Garber pools resembling Pennsylvania grade in their physical characteristics. They yield excellent steam-refined, filtered or bright stocks by the application of proper refining methods. From the very fact that crudes of this sort partake of the nature of several simpler varieties, it must be apparent that the design of such plants calls for an intimate knowledge of the technology of petroleum quite apart from purely engineering features. Economic conditions, however, frequently alter the situation so that skimming plants, operating even on crudes of superior lubricating base are exceedingly profitable, and the design of a simple typical Mid-Continent plant will therefore be discussed in part. It illustrates in principle the general method of individual plant design, a subject which it is manifestly impossible to cover in its multiplicity of detail in a book of this nature.

Consider, for example, a prospective plant of 1000 barrels daily capacity for operating on a crude of the following characteristics.

Characteristics of Blackwell, Oklahoma, Crude

Gr.	Color	Odor	Base	Sulphur
37.5	Green	Sweet	Paraffin-Asphalt	0.262 per cent

Laboratory Test Summary

		Per Cent
56/58	Gasoline, 450° End-point	27.3
50/52	Batching naphtha	3.7
41/43	Water-white kerosene	15.5
40/41	Prime-white kerosene	8.7
34/36	Light gas oil	8.3
24/26	Fuel oil	34.4
	Loss	2.1
	Total	100.00

Let it be assumed that the above test has shown that twenty-four to twenty-six hours running time on crude is necessary to effect a sufficiently complete separation

of products, and that 50 per cent of the original crude benzine must be steam-stilled to secure an end-point of 450° F. Let it be further assumed as demonstrated by test, that the steam-still bottoms and entire original prime-white cut must also be rerun to obtain color, and that all overhead products except the gas oil must receive either sodium plumbate, i.e., "doctor" treatment, or both acid and "doctor" treatment, to finish sufficiently sweet to stand inspection.

From the above data it follows that if twenty-six hours are necessary to strip 1000 barrels of crude in a 1000-barrel still, then a capacity equal to $\frac{2}{24}$ or $\frac{1}{12}$ over this figure would be theoretically necessary to strip the same quantity in twenty-four hours; i.e.,

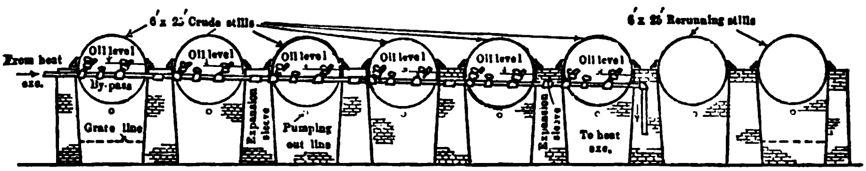


FIG. 5.—Rear-end elevation of continuous crude and batch rerunning stills.

1088 barrels still capacity. It has also been demonstrated empirically that practically the same separation can be obtained on a crude of this nature with 50 per cent to 60 per cent [1] less still capacity, and about an equal reduction in operating fuel, provided it be run continuously and that proper exchanging units have been installed. While therefore in the particular problem at hand, a capacity of 544 barrels would be theoretically sufficient, such computation would allow no shut-downs or cleaning, repairs, etc. Hence the figure of 544 should be increased by 10 per cent, the resultant amount 598, or in round numbers 600 barrels, being ample still capacity if correctly proportioned to the size of the plant. Here again empiricism, custom and good practice

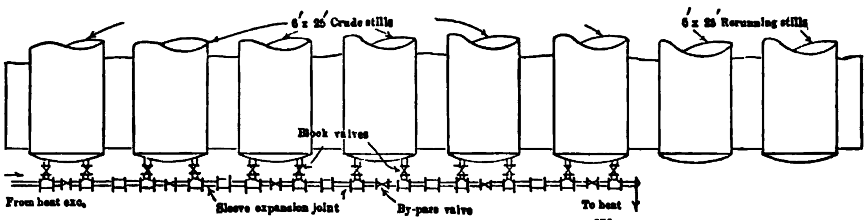


FIG. 6.—Plan of rear-end continuous crude and batch rerunning stills.

would unite in advocating six stills, 6 feet diameter by 25 feet long, each of 100 barrels charging capacity for a plant of this nature.

Similarly, basing the computation on 10 per cent of the daily crude refined to be rerun, requiring say thirty-six hours per batch, it may be shown allowing time for repairs, still-cleaning, etc., that two additional 100-barrel still units are a necessary part of the contemplated design for redistillation of steam-stilled bottoms and prime-white distillate. Fifty per cent of the initial crude benzine (which for purposes of discussion may be assumed as shown by preliminary laboratory tests to have been one-ninth greater than the combined gasoline and naphtha percentages) would then be 50 per cent of 34.4 per cent or 172 barrels daily of benzine to be steam-stilled. Assuming that experiments have further shown a unit quantity of benzine to require about seventy-

[1] This figure may be increased to 70 per cent and in some cases 80 per cent on small units where proper dephlegmating towers are installed. It is not uncommon to skim five times the actual charging capacity of a battery of small stills in twenty-four hours.

two hours for tower dephlegmation to secure the best results, a steam-still capacity of 3 times 172 barrels, or 516 barrels would then be theoretically required with no allowance for handling off-color and off-end-point batches at crude stills. The above figure should therefore be increased, say 25 per cent, to provide for such a contingency, and another 25 per cent for accumulation of water and bottoms, increasing the total amount to 747 barrels; or, in round numbers, two steam stills 10 feet in diameter by 30 feet long, each of 400 barrels charging capacity, would about fulfill the requirements. The stills described above are shown in elevation and plan the crude and steam stills connected to run continuously in Figs. 5, 6 and 7.

Condensing capacity.—In computing condensing capacity for a plant of this size,

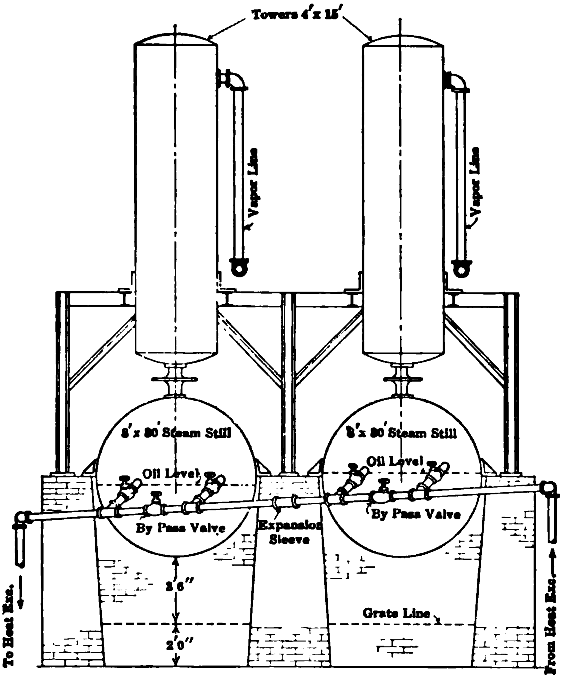


FIG. 7.—Rear-end elevation continuous tower steam stills.

the following empirical data, based on the assumption of 14 barrels of water at 70° F. being available for cooling purposes per barrel of distillate produced, will be found satisfactory and practical. More exact methods of determining areas of condensation surfaces are considered in the chapter on standard apparatus design.[1]

CONDENSING SURFACE REQUIRED PER BARREL OF DISTILLATE PRODUCED PER HOUR

Stills Using Both Fire and Steam

Stripping to "off gas-oil" (1½ pounds steam per gallon of distillate) = 50 square feet
Rerunning distillate (2½ pounds steam per gallon of distillate)......... = 70 square feet
Steam-stilling benzine (1½–10 pounds steam per gallon distillate)...... = 150 square feet

In determining the size of crude-still condensers in the plant under discussion, reference to the laboratory test shown on page 13 indicates that this crude will yield 65

[1] See p. 159.

per cent distillate, or, in terms of quantity, and of crude run, 650 barrels per twenty-four hours. This is distributed among five stills. Assuming that the sum of the flow of the first and last of the series only equals that of any one of the intermediate stills there

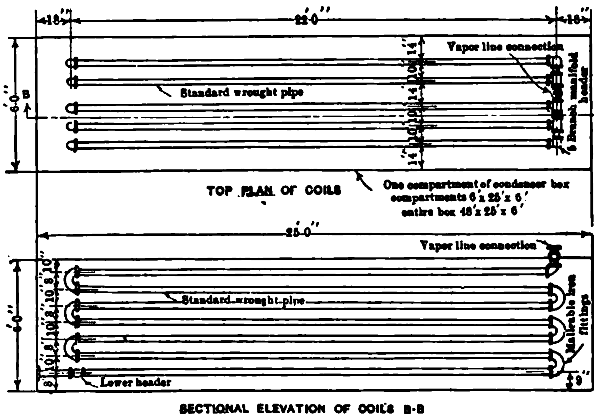


FIG. 8.—Typical compartment of a crude still condenser.

would be produced per hour per still $\frac{650}{24 \times 5}$ or 5.4 barrels. Further let it be assumed that at certain periods, on account of some one still of the series falling behind, that its flow must be forced for a short interval. Allowance should be made for double

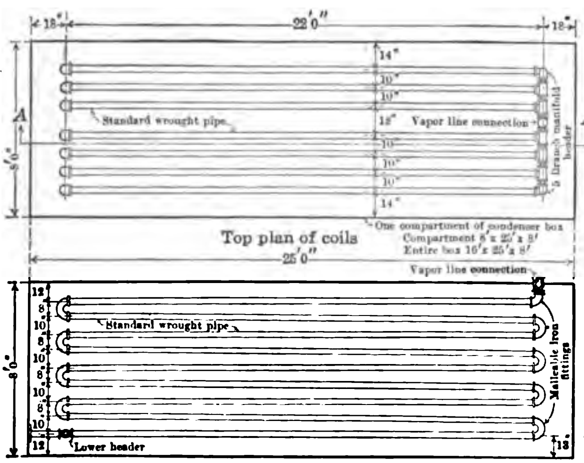


FIG. 9.—Typical compartment steam still condenser.

the regular quantity estimated, i.e., 2 by 5.4 or 10.8, or roughly 10 barrels. Applying the surface formula for stripping to gas-oil, an area of 10 feet by 50 feet, or 500 square feet would be required. Reduced to linear feet of say 2-inch pipe (0.6 square foot mean internal-external area per linear foot), $\frac{500}{0.60}$ or 833 feet of the latter would

be necessary. In round numbers 830 feet will be required to effect rapid condensation and avoid formation of pressure. A 5-manifold branch would be in order of $\frac{830}{5}$ or 166 feet to each section. Estimating the average length of the pipe to be 22 feet, including return bends, each coil section would be composed of $\frac{166}{22}$ or roughly 7 tiers. Since an odd number is necessary in order that the outlet of the coil be at the opposite end of the condenser to the vapor inlet, 7 rows would therefore be adopted. If the sections themselves are joined to a header on 10-inch centers, and spaced vertically 8 inches apart by slightly springing the return bends, which would be of malleable iron, a box would be evolved 6 feet in width by 6 feet in depth by 25 feet in length. Or in actual fabrication there would be a compartment condenser of 48 feet length by 25 feet width by 6 feet depth, divided into 8 compartments of the size above mentioned. Computation would show the two condensers necessary for rerun stills to be practically the same size as for crude stills. Similarly computed, the size of the steam-still condensers would figure 8 feet by 8 feet by 25 feet, with 7 sections, 9 pipes to the coil. Or in actual construction a two compartment box 25 feet long by 16 feet wide by 8 feet deep would be built. Both crude-still and steam-still types are illustrated in Figs. 8 and 9. In like manner the size of pumping out condensers or coolers may be computed, these being an auxillary or emergency necessity even where exchangers are installed. From the rough empirical figure of 14 barrels of water required per barrel of distillate produced, the water necessary for condensation, including that necessary for partial cooling of bottoms, may be figured as follows. Accurately compiled data for such work are given in a subsequent chapter.

Water Necessary for Condensation and Cooling

Barrels	
1000	Benzine, distillate, gas-oil and fuel.
100	Rerun distillate (including bottoms).
172	Heavy benzine (including bottoms).
1272	Total products to be condensed or cooled.
424	$33\frac{1}{3}$ per cent for forced periods.
1696	Grand total.

$$\frac{1696\times14\times42}{24\times60}=692.5 \text{ gallons per minute.}$$

Inasmuch as the water estimated in the preceding tabulation, after serving its purpose for condensation, can be used for boiler feed, and to a certain extent for washing in agitators, the above figure with an allowance of say 10 per cent for cold washing and miscellaneous uses, or roughly 660 gallons per minute, would constitute the plant's requirements. This amount would be reduced in proportion to subsequent recirculation where a cooling system is installed.

Heat exchange.—The scientific consideration of heat exchangers [1] is taken up at length in the chapter on standard apparatus design. The problem of proportioning an exchanger for the simple type of plant under discussion is easily solved by allowing a heat exchanging surface of 25 square feet per barrel of fuel oil produced per hour. Actual construction favors a counter-current pipe exchanger for the small quantities involved, as it is cheap and practical. The hot residuum passes through the pipes whose surface area is to be computed and the crude surrounds the same. Assuming that a series of 2-inch pipes (eight in number) is inserted in an outer 10-inch jacket and welded into tube sheets placed just within the ends of the 10-inch pipe, their length may be easily

[1] See p. 181.

ascertained. Thus, the mean internal-external area of 2-inch pipe being 0.60 square foot per linear foot, we have:

$$\frac{35 \text{ per cent} \times 1000 \times 25}{24} = 364.5 \text{ square feet of pipe surface;}$$

$$\frac{364.5}{0.60} = 607.5 \text{ linear feet of 2-inch pipe;}$$

$$\frac{607.5}{8} = 75.9 \text{ feet(8 in parallel 2-inch pipe).}$$

From the above it is evident that two parallel units of 10-inch pipe, each 38 feet long containing eight 2-inch pipes would be an excellent practical arrangement. Such a form of exchanger is illustrated in vertical section in Fig. 10.

Steam requirement.—The steam necessary to process a small skimming plant

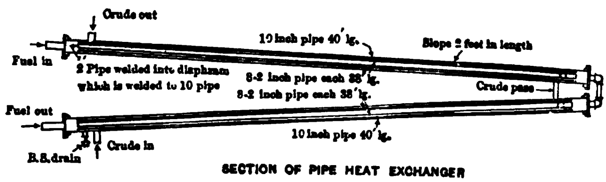


FIG. 10.—A section of a pipe heat exchanger.

similar to the one under discussion may also be figured from empirical considerations on the basis of the appended table.

Skimming Plant Process Steam Requirements in Horsepower per Barrel of Distillates Produced in Stills Using Both Fire and Steam

	H.P.
Stripping to "off gas-oil"	2.1
Rerunning distillate	3.5
Steam-stilling benzine (1st 50 per cent)	2.1
Steam-stilling benzine (2d 50 per cent)	14.06

Referring again to the laboratory yield, and applying the above data to the present problem, we have:

		H.P.
Steam used in stripping	$= \frac{650}{24} \times 2.1 =$	56.9
Steam used in rerunning	$= \frac{100}{24} \times 3.5 =$	14.6
Steam used in steam-stilling	$= \frac{86}{24} \times 2.1 =$	7.5
Steam used in steam-stilling	$= \frac{86}{24} \times 14.06 =$	50.2
		129.2
Steam used in forced periods (add 50 per cent)		64.8
Total steam used in process		194.0

By further simple methods of computation the steam necessary for heating and pumping purposes may be estimated at 50 additional horsepower, or a total of 244. For operating boilers at 80 per cent of their rating, amply sufficient with the usual refinery feed water, the nominal rating over the actual requirements would be $\frac{244}{80}$ or 305. In other words two 150- or three 100-H.P. boilers would carry the load of the plant without overcrowding.

Agitator capacity.—Assuming that all the overhead products except gas-oil require treating in some form, the agitator capacity would figure 58 per cent of the crude oil, or 580 barrels daily. The entire treating of such a plant could theoretically be handled with ease in ten hours, and the nominal agitator capacity be thereby reduced over 50 per cent; but such construction would be undesirable unless the concern is exceedingly limited in financial resources. Slight slips in the process would mean regular night treating with its greater chance for loss and would not be considered the best refinery practice. One agitator of 375 barrels capacity would be a more practical unit for a plant of such size.

Tankage.—In regard to tankage, in general one or preferably two run-down tanks should be installed for each grade of the product cut at a still, including a slop tank, all of sufficient capacity to avoid more than one pumping daily. It is, however, admitted in many plants that the size of run-down tanks is a matter of tradition and custom rather than of expediency. Two small tanks are always better than one large one, even though their initial cost be greater, because more regular and continuous operation of the process is assured when one of a pair is off for cleaning or repairs. Furthermore it is difficult accurately to compute the daily balance sheet in a plant where single run-down tanks are used, on account of a condition frequently met, where oil is run into a tank and pumped out at the same time. In the simple type of plant under discussion, however, with the few products refined, an excellent working layout would consist of one tank per product cut at crude and rerunning stills, including slop, with an extra in reserve making about eight tanks, with four at the steam stills or twelve 500-barrel tanks in all. In simple construction of the above type, the so-called working tanks of larger refineries are scarcely necessary. Only bleachers for refined oil and field storage tanks remain to be considered as major points of design.

Bleachers.—The bleachers may be disposed of with the statement that there should be two for each grade of refined oil, so that the clear oil in one tank need not be dimmed by the dropping of a fresh batch. In size they should obviously be large enough to hold a full batch from the agitator, with excess room for expansion when heated or blown, amounting in volume to 10 per cent. Thus in this design four 300-barrel bleacher tanks are required.

Storage tanks.—While still and agitator capacity, and the size of the run-down tanks can be scientifically worked out for any refining problem, storage tanks are dependent upon so many conditions that a special topic has been assigned to them, as affecting refinery design. In a simple plant of the type under discussion, a month's storage for crude, burning oil, gas-oil, and gasoline products, with a two months' supply for fuel oil would not be an uncommon arrangement. Although a few skimming plants possess much greater reserve, many of the smaller ones cannot run longer than three or four days without a shipment of some commodity. On the above basis the typical plant's field storage would be apportioned as follows:

Typical Field Storage Tanks of a 1000-Barrel Skimming Plant

	Tanks	Barrels
Crude	(2)	15,000
Water-white distillate	(2)	2,500
Prime-white distillate	(1)	2,500
Water-white kerosene	(1)	1,000
Prime-white kerosene	(1)	1,000
Gas-oil	(2)	1,000
Crude benzine	(2)	2,500
Gasoline and naphtha	(4)	1,000
Fuel oil	(2)	10,000

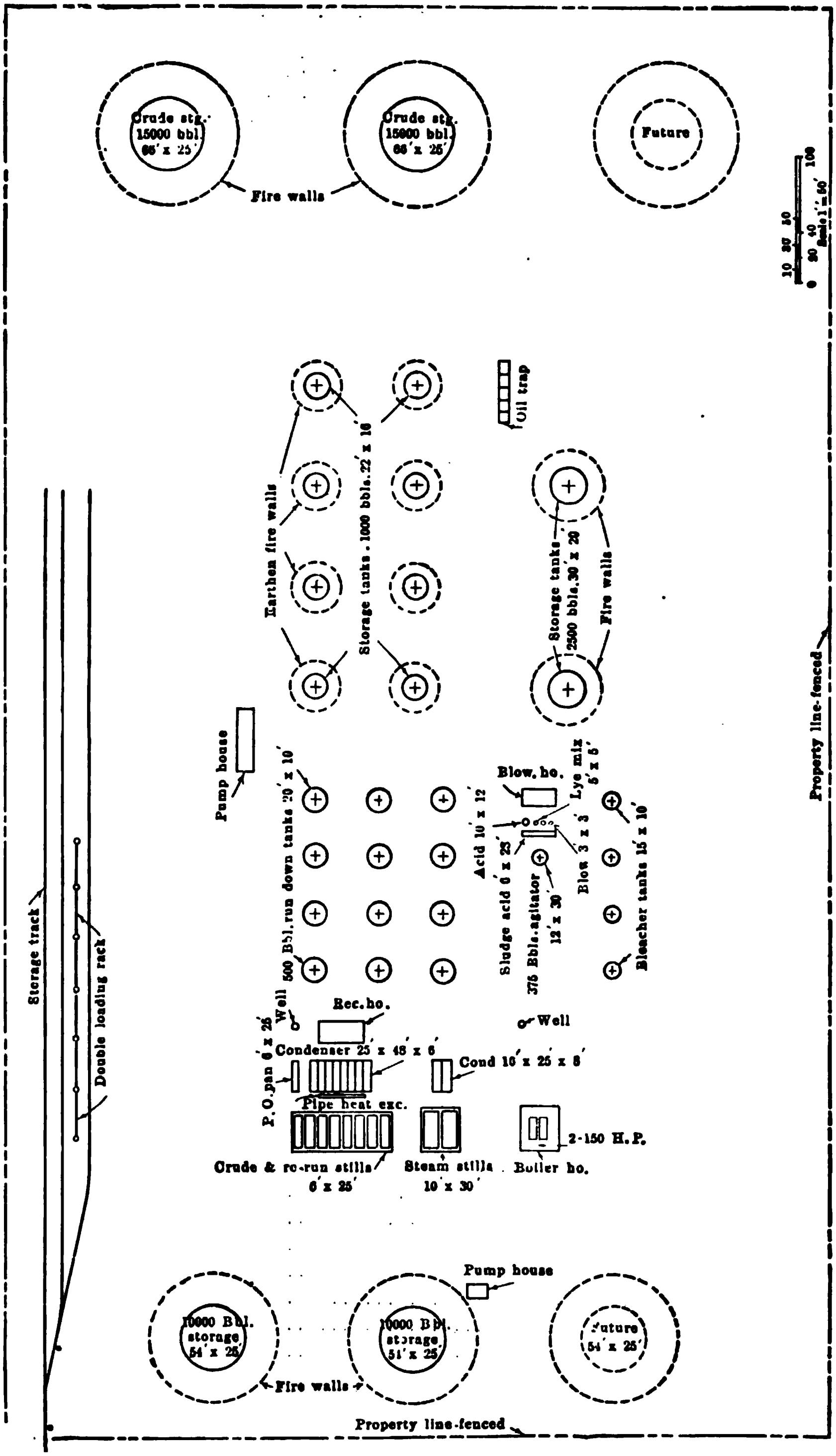


FIG. 11.—Layout of a 1000-barrel skimming plant.

Complete fabrication specifications for plate work in the typical 1000-barrel plant recently discussed, including certain items not previously mentioned, will be found on pages 24–40. A layout map is shown in Fig. 11. By applying the same principles

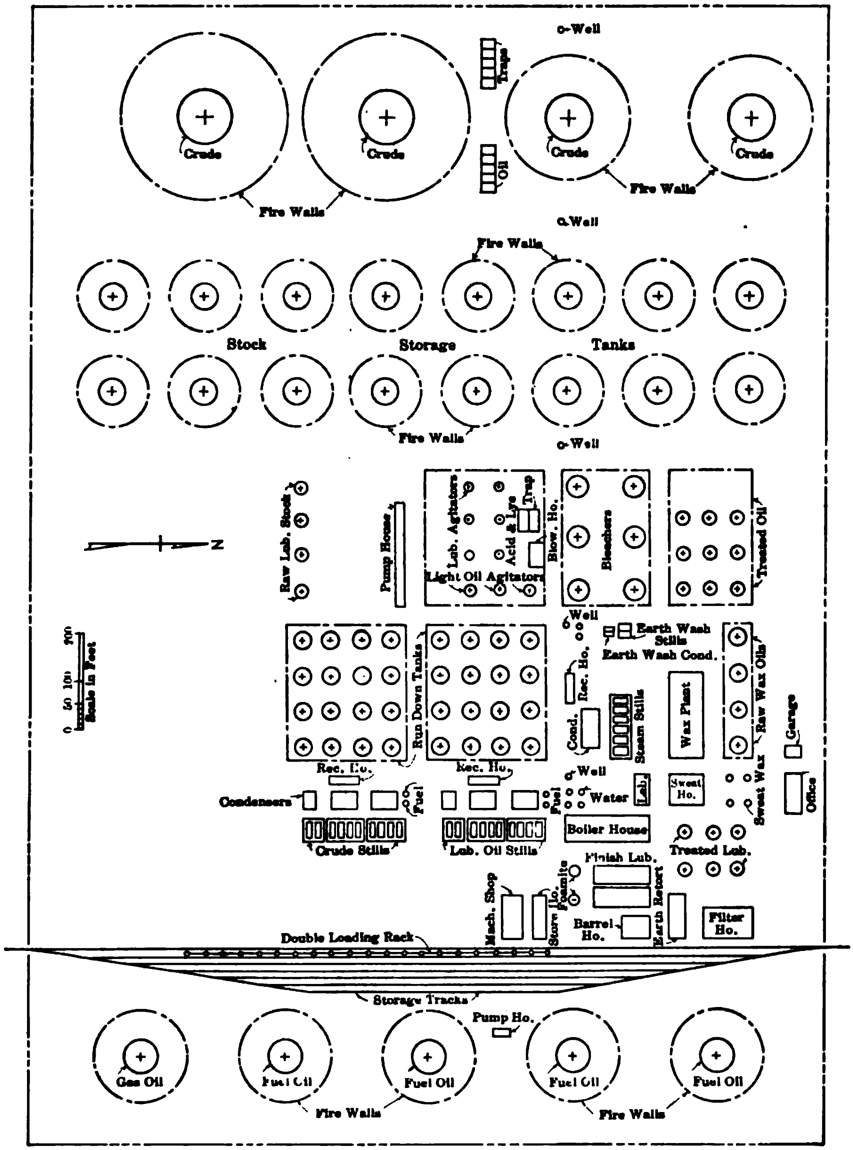


FIG. 12.—Layout 6000-barrel plant running to flux and lubricating oils.

as mentioned in the immediately preceding paragraphs, in conjunction with the more accurate and scientific methods of computation discussed in the sections devoted to apparatus, the design for Mid-Continent plants running to asphalt flux, paraffin wax,

FIG. 13.—Front view. Plant of The Milliken Co., at Arkansas City, Kans.

FIG. 14.—Rear view. Plant of The Milliken Co. at Arkansas City, Kans.

neutrals or red oils, or wax, paraffin oils and coke, may be similarly worked out. The lists of equipment together with fabrication specifications on pages 41–78 give an idea of current engineering practice for a 6000-barrel plant of this order. The layout of such a plant is shown in Fig. 12, and the illustrations shown in Figs. 13 and 14 give an excellent idea of the appearance of such construction.

The engineer is called upon for a wide variation in style of construction in plants operating on the grades of crude thus far discussed. The design of a Pennsylvania plant is practically standardized as far as the process is involved. It concerns itself especially with additions to the older plants and with overcoming engineering difficulties presented by lack of space, with the frequently conflicting objectives of efficiency and fire hazard. Aside from these features, and the obviously different construction of earlier periods, the real basic difference in the design of modern Pennsylvania plants is in filtering capacity, i.e., whether the plant is operated principally for high fire test steam-refined stocks, or for filtered or bright stocks of medium test. Installation of at least a minimum filtering capacity and wax plant equipment for neutrals, paraffin wax, etc., is practically universal as are likewise departments for cooperage and barrel filling.

Steel plate construction.—In the specifications for steel plate construction which follow, an attempt has been made to combine the best standard practice with experience gained in refinery operation. Where certain standards have been adopted with little change, credit has been given to the manufacturer, but in the main the schedules presented represent a combination of specifications of a value generally accepted by refinery engineers and modified by operating conditions rather than by any one manufacturer's system of design.

The specifications for the 1000-barrel skimming plant immediately following, are taken largely from a recent professional report. Those for the 6000-barrel plant running to flux and lubricants are compiled principally from the author's original specifications for a refinery erected at Arkansas City, Kansas, a few years ago, but revised and modified in the light of operating experience and more modern fabrication methods. Obviously it will be understood that detailed specifications of only the more general items of refinery plant work can be included in the following schedules, it being impossible to discuss secret, semi-secret, or partially developed apparatus or processes. It is believed, however, that such general specifications, in combination with the preceding discussion on design will be of value to the refiner, student, or reader who desires condensed, empirical, working data. The chapters on standard and special apparatus afford more detailed information to those desirous of giving greater consideration to the subject of design.

In considering the specifications for refining plants certain rules may be adopted as general for all construction. These include:

1. An acceptance shall be given in writing to the foreman of erection, which acceptance shall be considered as final. However, the purchaser shall have the right to maintain a competent inspector to follow the progress of the work. He shall have full authority to condemn any defective rivets or riveting, caulking or otherwise unworkmanlike assembly.

2. All the plate and rivets used in the fabrication of the equipment shall be of the best quality and conform to the standards of the associations of steel manufacturers for the various grades used.

3. Purchaser shall have inspection privilege before shipment if so desired.

4. Rivet holes shall be accurately spaced. They shall be clean, without ragged edges, and shall not require the use of drift pins, except to bring the plates together for assembly. All the rivets shall be spaced in accordance with the best acknowledged boiler work practice.

Specifications for the Steel Plate Work for a 1000-bbl. Skimming Plant

General Items

		Barrels
8	Crude stills, 6 feet diameter×25 feet long	100
2	Steam stills, 10 feet diameter×30 feet long	400
2	Steam still towers, 4 feet diameter×15 feet high	
1	Crude still condenser box, 48 feet long×25 feet wide×6 feet deep, divided into 8 compartments 25 feet long×6 feet wide×6 feet deep.	
1	Steam still condenser box, 25 feet long×16 feet wide×8 feet deep, divided into 2 compartments 25 feet long×8 feet wide×8 feet deep.	
1	Pumping-out pan, 25 feet long×6 feet wide×3 feet deep.	
1	Agitator, 12 feet diameter×30 feet high	375
2	Storage tanks, 66 feet diameter×25 feet high	15,000
2	Storage tanks, 55 feet diameter×25 feet $3\frac{3}{4}$ inches high	10,000
4	Storage tanks, 30 feet diameter×20 feet high	2,500
8	Storage tanks, 22 feet diameter×15 feet high	1,000
12	Run-down tanks, 20 feet diameter×10 feet $2\frac{3}{4}$ inches high	500
4	Bleacher tanks, 20 feet diameter×8 feet high	400
1	Acid tank, 10 feet diameter×10 feet high	125
1	Acid blow-case, 3 feet diameter×4 feet long	
		Gallons
2	Lye tanks, 5 feet diameter×4 feet high	500

General Steel and Tower Specifications

1. All plates shall be properly and neatly bevel-sheared for caulking by a rotary beveler. The corners shall be further scarfed to insure tight joints at laps. Horizontal seams shall be caulked inside and out.

2. All flanges except tar plug flanges and flow flanges shall be of standard medium heavy-forged steel type known as boiler flanges. Tar plugs and flow flanges shall be of medium heavy-forged steel, the former turned on bottom face to seat a 50° conical plug, and the latter especially constructed, with provision made for the dish of the end of the still, so that the axis of each flange shall be parallel to the axis of the still. Where long hub flanges are specified, an inside and an outside flange may be used in combination instead. Previous to application, flanges shall be fitted with C. I. plugs, screwed up moderately tight to prevent damage to threads.

3. Each still shall be equipped with a 3-inch conical C. I. tar plug operating in a special outlet flange. The plug shall be attached to a rod passing through a guiding strap on the inside of the shell, and the stuffing box on the top of the still. It shall be raised or lowered from any desired level by a pull handle of convenient length through the agency of a simple lever device. The plug shall be turned at an angle slightly different from that of the outlet flange, to avoid binding, that is, at approximately 50°, and shall not exceed 6 inches in height nor over 15 pounds in weight, exclusive of rod.

4. Stills and towers shall be fabricated complete in the shop, except the application of the lugs. They shall be tested under 15 pounds hydrostatic pressure, and shall be made absolutely watertight.

5. After testing, each still or tower shall be painted on the outside with one coat of approved protective paint.

Specifications for Eight Crude Stills Each 100 Barrels Capacity

Dimensions.—Stills shall be of horizontal type 6 feet in diameter by 25 feet long in the shell.

Shell.—The bottoms of the stills shall be made in one piece of 20.4-pound plate, of the best quality of firebox steel, 108 inches wide running the full length of the still. The top or crown sheets are to be made of three courses running girth-wise, of ⅜-inch or 15.3-pound flange steel.

Heads.—Heads shall be made from one piece of 20.4-pound plate, of best quality of flange steel, standard O.D., and flanged-in.

Dome.—Stills shall be provided with domes 30 inches in diameter by 30 inches high, and shall be constructed of ⅜-inch or 15.3-pound flange steel. The shell and head are each to be formed from one piece of plate. The head is to be standard O.D. and flanged-in. Domes shall be centered 4 feet from rear end of still, top of shell, on a line midway between the lugs.

Lugs.—Stills shall be supported by means of ten cast-iron or pressed-steel lugs, five on each side of a still. The line through the base of opposite lugs shall pass through the center axis of the still.

Riveting.—The roundabout seams of the crown sheets, and the vertical and horizontal seams of the dome shall be single riveted. All other seams shall be double riveted with ¾-inch rivets; lugs to shell with 1-inch rivets. All rivets shall be of cone-head type. They must completely fill the holes and have full heads not less than ½-inch in height, with centers in line with the centers of the rivet body.

Caulking.—The roundabout seams and dome shall be caulked on the outside only.

Flanges.—The following sizes of flanges shall be furnished:

Flanges for all Stills

1 6-inch vapor flange, single hub, located at center of right-hand side of dome, right and left sides to be determined when facing rear end.

1 4-inch charging flange, long hub, located at top of shell, on center line between lugs, 12 feet from rear end.

1 1½-inch steam flange, long hub, located at top of shell, on center line between lugs, 16 feet from rear end.

1 2-inch fire steam flange, single hub, located at top of shell, on center line between lugs, 17 feet from rear end.

2 1¼-inch tell-tale flanges, single hub, located at rear head of still, one centered 2 feet to right of perpendicular line through the center of the rear head, on a line 1 foot above the bottom of the still, and one directly above on a line 1 foot from the top of the still.

1 3-inch tar-plug flange, single hub, located bottom of shell, on center line between lugs, 9 inches from rear end.

Four Stills

2 4-inch flow flanges, long hub, located at rear head of still, centered 36 inches apart, equidistant from center of end, on a horizontal line 24 inches above the bottom of the still.

Four Stills

2 3-inch flow flanges, long hub, located at rear head of still, centered 36 inches apart, equidistant from center of end, on a horizontal line 24 inches above the bottom of the still.

Charging Cock Taps

No. 1 tap, rear head on center perpendicular line 18 inches below top of still.
No. 2 tap, 3 inches to right of center, 21 inches below top of still.
No. 3 tap, 3 inches to right of No. 2 tap, 24 inches below top of still.

NOTE.—All taps should be for ½-inch pipe.

Manheads.—Each still shall be equipped with one 18-inch quick-opening cast-iron manhead, complete with cover, cross-bar and screw. The seat casting shall be grooved for lime packing, and the cover provided with a corresponding projecting annular ring. The manhead shall be located at the top of the shell, on the center line between the lugs, 10 feet from the rear end.

Mannecks.—Each still shall be provided with one 18-inch forged manneck on the front end of the still, centered 2 feet from the bottom, and be so constructed that its axis shall be parallel to the axis of the still, in other words, horizontal. Each manneck shall have the bolt flange beaten out of one piece of ½-inch plate, rather than made from an angle ring, and shall finish ⅜-inch after facing. The manplate shall be of 7/16-inch material, faced in from the edge, to a distance equivalent to the facing of the flange, and shall be further provided with a crane support to hold the plate when it is not in use. The plate shall be secured by 22 ¾-inch square-shouldered still bolts with the shoulders fitting in square holes cut in the flange of the neck.

Two Steam Stills of 400 Barrels Capacity

Dimensions.—Stills shall be of horizontal type 10 feet in diameter by 30 feet long in the shell.

Shell.—The bottom of the still shall be made in two pieces of 17.85-pound plate, of the best quality of flange steel,[1] 108 inches wide, running the full length of the still. Top or crown sheets shall be made of four courses running girth-wise, of ⅜-inch or 14.3-pound tank steel.

Heads.—Heads shall be made from one piece of 17.85-pound plate, of the best quality of flange steel, standard O.D., and flanged-in.

Dome.—See flange specifications.

Lugs.—Stills shall be supported by means of twelve cast-iron or pressed-steel lugs, six on each side of the still. The line through the base of the lugs shall pass through the center axis of the still.

Riveting.—The roundabout seams of the crown sheets shall be single riveted; the horizontal seams double riveted with ¾-inch rivets; lugs to shell with 1-inch rivets. All rivets shall be of cone-head type, must completely fill the holes and have full heads not less than ½-inch in height.

Caulking.—The roundabout seams shall be caulked on the outside only.

Flanges.—The following sizes shall be furnished for each still:

1 12-inch vapor flange, single hub, located at top of shell, on center line between lugs, 8 feet from rear end.
1 4-inch charging flange, long hub, located at top of shell, on center line between lugs, 14 feet from rear end.
1 3-inch exhaust steam flange, long hub, located at top of shell, on center line between lugs, 18 feet from rear end.
1 2-inch live steam flange, long hub, located at top of shell, on center line between lugs, 19 feet from rear end.

[1] On account of the necessity of firing steam stills when running heavy naphtha, flange steel is specified for the bottom sheet. Tank steel is of sufficiently good quality for girth sheets, on account of comparatively low operating temperature.

2 $1\frac{1}{2}$-inch tell-tale flanges, single hub, located rear head of still, one centered 2 feet to right of perpendicular line through center of rear head, on a line 1 foot above bottom of still, and one directly above on a line 1 foot from top of still.

2 4-inch flow flanges, long hub, located at rear head of still centered 84 inches apart, equidistant from center of end, on a horizontal line 36 inches above bottom of still.

1 3-inch tar plug flange, single hub, located at bottom of shell, on center line between lugs, 9 inches from rear end.

Charging Cock Taps:

No. 1 tap, rear head on center perpendicular line, 24 inches below top of still.
No. 2 tap, 3 inches to right of center, 27 inches below top of still.
No. 3 tap, 3 inches to right of No. 2 tap, 30 inches below top of still.

NOTE.—All taps should be for $\frac{1}{2}$-inch pipe.

Manheads.—Each still shall be equipped with one 18-inch quick-opening cast-iron manhead, complete with cover, cross-bar and screw. The seat casting shall be grooved for lime packing, and the cover provided with a corresponding projecting annular ring. The manhead shall be located at the top of the shell, on the center line between the lugs 12 feet from rear end.

Mannecks.—Each still shall be provided with two 18-inch wrought-iron mannecks, one on each end of the still, centered 1 foot 6 inches from the bottom, and so constructed that their axes shall be parallel to the axis of the still, in other words, horizontal. Each neck shall have the bolt flange beaten out of one piece of $\frac{1}{2}$-inch plate, rather than made from an angle ring, and shall finish $\frac{3}{8}$-inch after facing. The manplate shall be of $\frac{7}{16}$-inch material, faced-in from the edge, to a distance equivalent to the facing of the flange, and shall be further provided with a crane support to hold the plate when it is not in use. The plate shall be secured by 22 $\frac{3}{4}$-inch square-shouldered still bolts, with the shoulders fitting in square holes cut in the flange of the neck.

Two Steam Still Towers

Dimensions.—Towers shall be of the vertical type, 4 feet in diameter by 15 feet high.

Shell.—This shall be made of three or four courses running girth-wise, of $\frac{3}{8}$-inch or 15.3-pound soft open-hearth tank steel. Vertical seams shall be staggered at approximately equal intervals.

Heads.—Heads shall be made from one piece of 20.4-pound plate of best quality flange steel, standard O.D., and flanged-in.

Lugs.—Each tower shall be provided with four lugs approximately 14 inches wide by 36 inches long, or of a proper size to develop sufficient strength to support the tower in vertical position full of water. Lugs shall be centered 90° from each other the bases to lie on a line 8 inches above the bottom of the shell.

Riveting.—All roundabout seams shall be single riveted with $\frac{3}{4}$-inch rivets, spaced $2\frac{1}{4}$ inches between centers. All vertical seams shall be double riveted with $\frac{3}{4}$-inch rivets, spaced $1\frac{3}{4}$ inches between centers.

Caulking.—All seams shall be caulked on the outside only.

Flanges.—The following sizes of flanges shall be furnished for each tower:

1 12-inch inlet flange, single hub, centered in bottom of tower.

1 6-inch vapor flange, single hub, located shell of tower on a line 18 inches below top and passing vertically through vertical axis of one of the supporting lugs.

4 1-inch supporting flanges, single hub, top of tower, two located on a line passing through center of tower and 45° to line passing through any two lugs; two on a line at 90° to first line, also passing through center of the tower; all four flanges to be centered on a circle of 4 feet diameter.

1 3-inch charging flange, long hub type, located shell of tower on a line 18 inches below rop, entering directly opposite the 6-inch vapor flange.

Mannecks.—Each tower shall be provided with two 18-inch cast-iron mannecks, one centered at the top of the tower; the other in the side of the shell centered 24 inches from the bottom on a line midway between two adjacent lugs. The necks shall have a bolt flange turned true, and the plates shall also be faced-in to a distance from the edge equivalent to the facing of the flange. The side plate shall further be provided with crane support, and both plates shall be secured by 22 ¾-inch standard bolts only.

Gratings.—Each tower shall be provided with a set of gratings or false bottom, to be supported 4 feet above the bottom of the tower by a ⅜-inch by 2½-inch angle ring, riveted around inside the shell, and by two angles of the same weight framed across the shell. Grating plates shall be cut in strips sufficiently narrow to pass through the mannecks; they shall rest without fastening on grating supports, and shall be perforated with as many 4-inch holes as can be readily punched in the sheets.

One Crude Still Condenser Box

Dimensions.—The condenser shall be rectangular in shape, 48 feet long, by 25 feet wide, by 6 feet deep. It shall be divided into eight compartments by partitions parallel to the 25-foot side, each compartment being 25 feet long, by 6 feet wide, by 6 feet deep, with an open top throughout.

General construction.—The condenser shall be constructed in five courses for each 25-foot side or partition. Each course shall be formed of single plates bent at the lower edge to a radius of 3 inches, thus forming, the side and various compartments of the condenser. The long 48-foot sides shall be formed of appropriate courses, and flanged-in where the side sheets join the end sheets. Soft open-hearth tank steel conforming to the standard of the Association of American Steel Manufacturers shall be used throughout as plate material, of ¼-inch thickness or 10.20-pound weight.

Angle bracing.—The sides of the condenser shall be reinforced by 5/16-inch by 2¾-inch by 2¾-inch angles running completely around the top of the box and across the partition sheets. The joints shall be neatly butted and fastened with butt straps. The sides of the condenser shall be stiffened on the inside walls by vertical angles. There should be seven angles ⅜ inch by 2¾ inches by 2¾ inches per 25-foot side, spaced equally distant, and one angle ⅜ inch by 2¾ inches by 2¾ inches per 6-foot side, all extending from the top to the bottom of the condenser.

Cross ties.—The vertical angle units shall be tied together by ¼-inch by 2-inch flats running crosswise of the compartments, midway between top and bottom and parallel to the latter. The vertical units shall be similarly tied together at the top of the condenser by ¼-inch by 2½-inch flats. In addition a series of diagonal ties of equal weight shall be bolted to longitudinal reinforcing angles.

Riveting.—All seams shall be single riveted with ⅜-inch diameter rivets, spaced 1¼-inch between centers, of the quality known as mild-steel tank rivets, conforming with the standards of the Association of American Steel Manufacturers. The rivets of the top angles and the vertical stiffeners shall be spaced on 3-inch and 6-inch centers respectively.

Caulking.—The bottom of the condenser shall be caulked on the inside, the sides on the outside.

Flanges.—All of the flanges shall be of a standard light-forged steel type, known as tank flanges. Eight 3-inch and eight 2-inch flanges shall be furnished and applied in the field.

Testing.—The condenser is to be shipped completely knocked down, and erected in the field on foundations prepared by the purchaser. It shall be tested full of water when finished. Each compartment shall be caulked tight separately, as well as the condenser as a whole.

One Steam Still Condenser Box

Dimensions.—The condenser shall be rectangular in shape, 25 feet long by 16 feet wide by 8 feet deep. It shall be divided into two compartments by a partition parallel to the 25-foot side, each compartment being 25 feet long by 8 feet wide by 8 feet deep with an open top throughout.

General construction.—The condenser shall be constructed in five courses for each 25-foot side or partition. Each course shall be formed of one or two plates, the lower course to be bent at the lower edge to a radius of 4 inches, thus forming the sides of the condenser and its central partition. The short 16-foot ends shall be formed of appropriate courses, and flanged-in where the side sheets join the end sheets. Soft open-hearth tank steel, shall be used throughout as plate material, of 5/16-inch thickness or 12.75-pounds weight.

Angle bracing.—The sides of the condenser shall be reinforced by 5/16-inch by 2½-inch by 2½-inch angles running completely around the top of the box and across the partition sheet. The joints shall be neatly butted and fastened with butt straps. The sides of the condenser shall be stiffened on the inside wall by vertical angles. There shall be seven 3/8-inch by 2½-inch by 3-inch angles per 25-foot side, spaced equally distant, and one 3/8-inch by 2½-inch by 3-inch angle per 8-inch side, all extending from the top to the bottom of the condenser.

Cross ties.—The vertical angle units shall be tied together by ¼-inch by 2-inch flats running crosswise of the compartments, midway between the top and bottom and parallel to the latter. The vertical units shall be similarly tied together at the top of the condenser by ¼-inch by 2½-inch flats. In addition a series of diagonal ties of equal weight shall be bolted to longitudinal reinforcing angles.

Riveting.—All seams shall be single riveted with 5/8-inch diameter rivets, spaced 1¾ inches between centers, of quality known as mild-steel tank rivets. The rivets of the top angles and the vertical stiffeners shall be spaced on 3-inch and 6-inch centers respectively.

Caulking. The bottom of the condenser shall be caulked on the inside, the sides on the outside.

Flanges.—Two 3-inch and two 2-inch flanges shall be furnished and applied in the field.

Testing.—The condenser is to be shipped completely knocked down, and erected in the field on foundations prepared by the purchaser. It shall be tested full of water when finished. Each compartment is to be caulked tight separately as well as the condenser as a whole.

One Pumping-out Pan

Dimensions.—The pan shall be rectangular in shape, 25 feet long, by 6 feet wide, by 3 feet deep, of open top construction.

General construction.—The pan shall be constructed in four or five courses of single plates bent on 3-inch radii to form the sides of the pan. The ends shall be made from one piece of plate and flanged-in where the side sheets join. Soft open-

hearth tank steel shall be used throughout as plate material, of ¼-inch thickness, or 10.20 pounds weight.

Angle bracing.—The sides of the pan shall be reinforced be 5/16-inch by 2½-inch by 2½-inch angles running completely around the top of the pan. The joints shall be neatly butted and fastened with butt straps.

Cross ties.—A series of diagonal ties of ¼-inch by 2½-inch flats shall be bolted to longitudinal reinforcing angles at appropriate distances for strengthening purposes.

Riveting.—All seams shall be single riveted with ⅝-inch diameter rivets, spaced 1¾-inch, centers of quality known as mild-steel tank rivets. The rivets of the top angles shall be spaced on 3-inch centers.

Caulking.—The bottom of the pan shall be caulked on the inside, the sides on the outside.

Flanges.—The pan shall be provided with one 3-inch, and one 2-inch standard forged-steel tank flange, both to be applied in the field.

Testing.—The pan shall be fabricated complete in the shop and shall be tested as usual.

One Agitator of 375 Barrels Capacity [1]

Dimensions.—The agitator shall be of vertical type, closed top, 12 feet in diameter by 30 feet high.

General construction.—The agitator shell shall be constructed throughout of mild open-hearth tank steel in the following weights:

Apron ring, 5/16-inch, 12.75-pound plate,
First ring, 5/16-inch, 12.75-pound plate,
Second ring, ¼-inch, 10.20-pound plate,
Third ring, ¼-inch, 10.20-pound plate.

In the apron ring there shall be a 3 by 6-foot door, the opening for which shall be braced with an angle ½ inch by 3 inches by 3 inches. Located at the base of the first ring the cone shall be constructed of six segmental plates of ⅜-inch flange steel, and one circular bottom plate of 7/16-inch like material. The cone shall be flanged to fit the inside of the shell with a flange of sufficient width for a double row of rivets.

Material.—All of the plates, rivets, and angles to be used in the fabrication of this agitator shall be of the best quality.

Angles.—Around the bottom of the apron there shall be two angles ⅜ inch by 4 inches, by 4 inches, inside and outside of the shell while around the top of the shell there shall be one angle 5/16 inch by 2½ inches, by 2½ inches turned out.

Riveting.—All of the seams in the apron ring shall be single riveted with ¾-inch rivets. All of the segmental seams in the cone shall be single riveted with ¾-inch rivets. The circular seams at the top of the cone shall be double riveted with ¾-inch rivets. The vertical seams in the first ring shall be double riveted with ⅝-inch rivets. These rivets shall be of cone-head type. All of the seams in the roof shall be single riveted with ⅝-inch rivets, which may be of flat-head tank-rivet type and driven cold if so desired.

Caulking.—All of the seams in the cone shall be caulked inside and outside, while all of the seams in the shell above the cone shall be caulked on the inside only.

Fittings.—These shall include:

1 4-inch C.E. nozzle with the upper flange cast to fit the agitator bottom plate, and the lower fitted with 4-inch tap companion flange, provided with necessary standard bolts.

[1] Agitator specifications in the accompanying schedule are adapted from the Graver Corporation E. Chicago, Ind., standards.

4 18-inch by 24-inch explosion hatches fitted with self-closing covers, to be applied on the roof, equidistant, as close to shell as good practice will allow.

1 Standard ventilator, located at center of roof.

Roof.—The roof shall be of the self-supporting umbrella type, constructed of eight segmental plates of 3/16-inch or 7.65-pound tank steel. The rise of the roof shall be about 18 inches. The roof shall be attached to the agitator by bolting to the top 5/16-inch by 2½-inch by 2½-inch reinforcing angle.

Stairway and gallery.—The agitator shall be provided with a standard gallery, which shall have a pipe railing and steel flooring. These shall be supported by means of structural steel brackets riveted to the shell. A stairway shall also be furnished, of standard steel construction with a suitable pipe railing.

Testing.—The agitator is to be shipped completely knocked down and is to be erected in the field on a foundation prepared by the purchaser. When finished it shall be tested full of water, and caulked tight to the satisfaction of the purchaser.

Two Storage Tanks of 15,000 Barrels Capacity[1]

Dimensions.—Tanks shall be of vertical type, tight steel roof, 66 feet in diameter by 25 feet high.

Material.—All of the plate, rivets, and angles used in fabrication shall be of the best quality.

General Construction.—Tanks shall be constructed throughout of mild open-hearth tank steel. The shell plates shall be joined to the bottom plates by means of an angle ring turned on the inside of the shell, to which both shell and bottom shall be riveted. The upper course of the shell shall be reinforced with an angle ring turned out, unless otherwise specified, to which the roof sheets shall be attached. Plates and angles shall be of the following weights and sizes:

Bottom rectangles	8.28 pounds	Third ring	9.56 pounds
Bottom sketches	8.28 pounds	Fourth ring	8.92 pounds
First ring	10.53 pounds	Fifth ring	8.28 pounds
Second ring	10.20 pounds	Roof plates	5.47 pounds
Bottom angle, ⅜-inch by 3½-inch by 3½-inch		Top angle, 5/16-inch by 2½-inch by 2½-inch	

Riveting.—All riveting shall conform to following schedule:

Bottom plates	Riveting bottom seams	
Rectangles..... / Sketches......	7/16-inch R., 1½-inch P., S.R.L.	
Bottom angle	**Riveting bottom angles**	
To bottom..... / To shell.......	⅝-inch R., 2¼-inch P., S. R.L.	
Rings	**Riveting circular seams**	**Riveting vertical seams**
1 to 2......... / 2 to 3.........	⅝-inch R., 2¼-inch P., S.R.L.	⅝-inch R., 2½-inch P., D.R.L.
3 to 4......... / 4 to 5.........	7/16-inch R., 2½-inch P., S. R.L.	7/16-inch R., 2¾-inch P., D.R.L.
5..		7/16-inch R., 1½-inch P., S.R.L.
Top Angle	**Riveting top angle**	
To shell.......	7/16-inch R., 2¼-inch P., S.R.L.	
Roof plates	**Riveting roof plates**	
To top angle ...	7/16-inch R., 1½-inch P., S.R.L.	
Plates.........	⅜-inch R., 2 -inch P., S.R.L.	

[1] Storage and run-down tank specifications in the following schedules are adapted from the standards of the Riter-Conley Manufacturing Company, Pittsburgh, Pa.

Shearing and caulking.—All the plates shall be properly and neatly bevel-sheared for caulking (angles excepted) bottom plates on inside, shell outside, roof not required.

Flanges.—Each tank shall be provided with the following flanges, which shall be made of standard forged steel of the type known as tank flanges. It shall be understood that where a long-hub type is specified, two standard tank flanges inside and out may be used in combination.

- 1 6-inch pumping-out flange, long hub, located shell, centered on a line 18 inches above bottom of tank and 2 feet to right of manhole.
- 1 4-inch pumping-in flange, single hub, located shell, centered on a line 10 inches below top and 2 feet to right of 6-inch pumping-out flange.
- 1 4-inch water draw-off flange, long hub, located shell, centered on a line 9 inches above bottom of tank and 4 feet to right of 6-inch pumping-out flange.
- 1 2½-inch steam fire flange, single hub, located shell, centered on a line 9 inches below top and 4 feet to right of 4-inch pumping-in flange.

Manholes.—All tanks shall be provided with two manholes: one 20-inch cast-iron manhole in the center of the first ring, the latter reinforced by a ⅜-inch by 40-inch by 40-inch plate at the point of attachment; one 20-inch steel plate neck, located in the roof of the tank as close to the shell as good practice will allow, and centered directly over the side neck. The angle ring of the lower neck shall be faced true as shall also the cast-iron cover plate for a corresponding distance. The top neck shall be provided with a light hinged cover closing gas-tight. Special gaging nipples, gas-vent pipes, or foamite connections will be installed on a cost plus basis, as requested by the purchaser.

Swing pipe.—All tanks shall be furnished with one 6-inch swing pipe, complete with wire cable and double windlass. The windlass box shall be located on the roof and shall be provided with a stuffing box for the crank shaft, also a gas-tight cover.

Stairway.—Each tank shall be provided with standard steel stairs and cab.

Roof supports.—The roof of each tank shall be supported by 8-inch channel rafters resting on circular purlin rings. These in turn shall be supported by columns of adequate strength.

Testing.—The bottom of each tank shall be tested with 4 inches of water as soon as the first ring is completed, before dropping from horses the test shall be final with respect to the bottom and the bottom angle. Upon the completion of the shell, the tank shall be again tested full of water and caulked tight.

Two Storage Tanks—10,000 Barrels

Dimensions.—These tanks shall be of vertical type with tight steel roofs, 55 feet diameter by 25 feet, 3⅞ inches high.

Material—General construction.—Tanks shall be constructed throughout of mild open-hearth tank steel. The shell plates shall be joined to the bottom plates by means of an angle ring turned inside of the shell, to which both the shell and the bottom shall be riveted. The upper course of the shell shall be reinforced with an angle ring turned out, unless otherwise specified, to which the roof sheets shall be attached. Plates and angles shall be of the following weights and sizes:

Botton rectangles	8.28 pounds	Third ring	8.92 pounds
Bottom sketches	8.28 pounds	Fourth ring	8.28 pounds
First ring	10.20 pounds	Fifth ring	8.28 pounds
Second ring	9.56 pounds	Roof plates	5.47 pounds
Bottom angle, ⅜ inch by 3 inches by 3 inches		Top angle, 5/16 inch by 2½ inches by 2½ inches	

Riveting.—All the riveting shall be in accordance with the best acknowledged standard practice and conform to the following schedule:

Bottom plates	Riveting bottom seams
Rectangles..... Sketches......	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.

Bottom angle	Riveting bottom angle
To bottom .... To shell.......	½-inch R., 2-inch P., S.R.L.

Rings	Riveting circular seams	Riveting vertical seams
1 to 2......... 2 to 3.........	½-inch R., 2-inch P., S.R.L.	½-inch R., 2¼-inch P., D.R.L.
3 to 4......... 4 to 5.........	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	$\frac{7}{16}$-inch R., 1¾-inch P., D.R.L.
5..		$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.

Top angle	Riveting top angle
To shell.........	$\frac{7}{16}$-inch R., 2¼-inch P., S.R.L.

Roof plates	Riveting roof plates
To top angle.....	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.
Plates...........	½-inch R., 2-inch P., S.R.L.

Shearing and caulking.—All the plates shall be properly and neatly bevel-sheared for caulking, angles excepted, bottom plates on inside, shell outside, roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 4-inch pumping-out flange, long hub, centered on a line 18 inches above bottom of tank and 2 feet to right of manhole.

1 4-inch pumping-in flange, single hub, centered on a line 10 inches below top and 2 feet to right of 9-inch pumping-out flange.

1 3-inch water drawer-off flange, double hub, centered on a line 8 inches above bottom of tank and 4 feet to right of 4-inch pumping-out flange.

1 2-inch steam fire flange, single hub, centered on a line 9 inches below top and 4 feet to right of 4-inch pumping-in flange.

Manholes.—The tanks shall be provided with two manholes; one 20-inch C.I. manhole in center of first ring. This shall be reinforced by a ½-inch by 40-inch by 40-inch plate at the point of attachment; one 20-inch steel plate neck, located at the roof of the tank as close to the shell as good practice will allow and centered directly over the side neck. The angle ring of the lower neck shall be faced true, as shall also the cast-iron cover plate for a corresponding distance. The top neck shall be provided with a light hinged cover, closing gas-tight. Special gaging nipples, gas-vent pipes, or Foamite connections will be installed on a cost-plus basis as requested by the purchaser.

Swing pipe.—The tanks shall be furnished with one 4-inch swing pipe, complete with wire cable and double windlass. The windlass box shall be located on the roof and be provided with a stuffing box for the crank shaft, and a gas-tight cover.

Stairway.—Each tank shall be provided with standard steel stairs and cab.

Roof supports.—The roof of each tank shall be supported by 7-inch channel rafters appropriately spaced and resting on a center circular purlin ring which shall be in turn supported by a structural column of adequate strength.

Testing.—The bottom of each tank shall be tested with 4 inches of water as soon as the first ring is completed. It shall be caulked tight before dropping from horses.

This test shall be final with respect to bottom and bottom angle. Upon the completion of the shell, the tank shall be again tested full of water and caulked tight.

Four Storage Tanks—2500 Barrels

Dimensions.—Tanks shall be of vertical type, tight steel roof, 30 feet diameter by 20 feet high.

Material.—All the plate, rivets, and angles used in fabrication shall be of the best quality.

General construction.—Tanks shall be constructed throughout of mild open-hearth tank steel. The shell plates shall be joined to the bottom plates by means of an angle ring turned inside of the shell, to which both shell and bottom shall be riveted. The upper course of the shell shall be reinforced with an angle ring turned out, unless otherwise specified to which the roof sheets shall be attached. The plates and angles shall be of the following weights and sizes:

Bottom rectangles	8.28 pounds	Third ring	8.28 pounds
Bottom sketches	8.28 pounds	Fourth Ring	8.28 pounds
First ring	8.28 pounds	Roof plates	5.10 pounds
Second ring	8.28 pounds	Top angle	$\frac{5}{16}$-inch by 2-$\frac{1}{2}$ in. by 2-$\frac{1}{2}$ in.

Bottom angle, $\frac{5}{16}$-inch by 2$\frac{1}{2}$-in. by 2$\frac{1}{2}$-in.

Riveting.—All the riveting shall conform to the following schedule:

Bottom plates	Riveting bottom seams
Rectangles	$\frac{7}{16}$-inch R., 1$\frac{1}{2}$-inch P., S. R. L.
Sketches	$\frac{5}{16}$-inch R., 1$\frac{1}{2}$-inch P., S. R. L.

Bottom angle	Riveting bottom angle
To bottom	$\frac{7}{16}$-inch R., 1$\frac{1}{2}$-inch P., S. R. L.
To shell	$\frac{7}{16}$-inch R., 1$\frac{1}{2}$-inch P., S. R. L.

Rings	Riveting circular seams	Riveting vertical seams
1 to 2	$\frac{7}{16}$-inch R., 1$\frac{1}{2}$-inch P., S. R. L.	$\frac{7}{16}$-inch R., 1$\frac{3}{4}$-inch P., D. R. L.
2 to 3	$\frac{7}{16}$-inch R., 1$\frac{1}{2}$-inch P., S. R. L.	$\frac{7}{16}$-inch R., 1$\frac{3}{4}$-inch P., D. R. L.
3 to 4	$\frac{7}{16}$-inch R., 1$\frac{1}{2}$-inch P., S. R. L.	$\frac{7}{16}$-inch R., 1$\frac{3}{4}$-inch P., D. R. L.
4	$\frac{7}{16}$-inch R., 1$\frac{1}{2}$-inch P., S. R. L.	$\frac{7}{16}$-inch R., 1$\frac{1}{2}$-inch P., D. R. L.

Top angle	Riveting top angle
To shell	$\frac{7}{16}$-inch R., 2$\frac{1}{4}$-inch P., S. R. L.
Roof plates	**Riveting roof plates**
To top angle	$\frac{7}{16}$-inch R., 1$\frac{1}{2}$-inch P., S. R. L.
Plates	$\frac{3}{8}$-inch R., 2-inch P., S. R. L.

Shearing and caulking.—All plates shall be properly and neatly bevel-sheared for caulking (angles excepted). The bottom plates on inside, shell outside, roof not required.

Manholes.—Tanks shall be provided with two manholes; one 20-inch cast-iron manhole in the center of the first ring, the latter reinforced by a $\frac{5}{16}$-inch by 40-inch by-40-inch plate at point of attachment; one 20-inch steel plate neck, located at the roof of the tank as close to the shell as good practice will allow and centered directly over the side neck. The angle ring of the lower neck shall be faced true as shall also the cast iron cover plate for a corresponding distance the top neck shall be provided with a light hinged cover which closes gas-tight. Special gaging nipples, gas-vent pipes

or foamite connections will be installed on a cost-plus basis as requested by the purchaser.

Flanges.—Each tank shall be provided with the following flanges:

- 1 4-inch pumping-out flange, long hub, located shell, centered on a line 18 inches above bottom of tank and 2 feet to right of manhole.
- 1 4-inch pumping-in flange, single hub, located shell, centered on a line 10 inches below top and 2 feet to right of 4-inch pumping-out flange.
- 1 3-inch water draw-off flange, single hub, located shell, centered on a line 8 inches above bottom of tank and 4 feet to right of 4-inch pumping-out flange.
- 1 2-inch steam fire flange, single hub, located shell centered on a line 9 inches below top and 4 feet to right of 4-inch pumping-in flange.

Swing pipe.—Tanks shall be furnished with one 4-inch swing pipe, complete with wire cable and single windlass. The windlass box shall be located on the roof and be provided with a stuffing box for the crank shaft, and a gas-tight cover.

Stairway.—Each tank shall be provided with standard steel stairs.

Roof supports.—The roof of each tank shall be laid on 24 $\frac{5}{16}$-inch by 3-inch by 3½-inch angle rafters clipped to the tank shell, and supported by one 5-inch center pipe column.

Testing.—The bottom of each tank shall be tested with 4 inches of water as soon as the first ring is completed, and shall be caulked tight before dropping from the horses. Upon the completion of the shell, the tank shall be again tested full of water and caulked tight, to the satisfaction of the purchaser.

Eight Storage Tanks—1000 Barrels

Dimensions.—Tanks shall be of vertical type, tight steel roof, 22 feet in diameter by 15 feet high.

Material.—All plate, rivets, and angles used in fabrication shall be of the best quality.

General construction.—Tanks shall be constructed throughout of mild open-hearth tank steel. The shell plates shall be joined to the bottom plates by means of an angle ring turned inside of the shell, to which both shell and bottom shall be riveted. The upper course of the shell shall be reinforced with an angle ring turned out, unless otherwise specified, to which the roof sheets shall be attached. The plates and angles shall be of the following weights and sizes:

Bottom rectangles . . . . 8.28 pounds
Bottom sketches . . . . 8.28 pounds
First ring . . . . 8.28 pounds
Bottom angle, $\frac{5}{16}$-inch by 2½ in. by 2½ in.
Second ring . . . . 8.28 pounds
Third ring . . . . 8.28 pounds
Roof plates . . . . 5.10 pounds
Top angle, $\frac{3}{16}$-inch by 2½ in. by 2½ in.

Riveting.—All the riveting shall conform to the following schedule:

Bottom plates	Riveting bottom seams
Rectangles . . . . . Sketches	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.

Bottom angle	Riveting bottom angle
To bottom . . . . . To shell	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.

Rings	Riveting circular seams	Riveting vertical seams
1 to 2......... / 2 to 3.........	$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.	$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.

Top angle	Riveting top angle
To shell.......	$\frac{7}{16}$-inch R., $2\frac{1}{4}$-inch P., S.R.L.

Roof plates	Riveting roof plates
To top angle ...	$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.
Plates	$\frac{3}{8}$-inch R., 2 -inch P., S.R.L.

Shearing and caulking.—All the plates shall be properly and neatly bevel-sheared for caulking, angles excepted, bottom plates on inside, shell outside, roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 4-inch pumping-out flange, long hub, located shell, centered on a line 18 inches above bottom of tank and 2 feet to right of manhole.

1 3-inch pumping-in flange, single hub, located shell, centered on a line 9 inches below top and 2 feet to right of 4-inch pumping-in flange.

1 3-inch water draw-off flange, single hub, located shell, centered on a line 8 inches above bottom of tank and 4 feet to right of 4-inch pumping-out flange.

1 2-inch steam fire flange, single hub, located shell, centered on a line 9 inches below top and 4 feet to right of 3-inch pumping-in flange.

Manholes.—Tanks shall be provided with two manholes; one 20-inch C. I. manhole in the center of the first ring, the latter to be reinforced by a $\frac{5}{16}$-inch by 40-inch by 40-inch plate at the point of attachment; one 20-inch steel plate neck, located at the roof of the tank as close to the shell as good practice will allow and centered 3 feet to the left of the side neck. The angle ring of the lower neck and the cast-iron cover plate shall both be faced true, for a corresponding distance; top neck to be provided with a light hinged cover, closing gas-tight. Special gaging nipples, gas vent pipes, or foamite connections will be installed on a cost-plus basis as requested by purchaser.

Swing pipe.—Tanks shall be furnished with one 4-inch swing pipe, complete with wire cable and single windlass. The windlass box shall be located on the roof and provided with a stuffing box for the crank shaft and also a gas-tight cover.

Ladder.—Each tank shall be provided with a standard steel ladder on the outside, located 3 feet to the left of the lower manhole.

Roof supports.—The roof of each tank shall be laid on by $12\frac{5}{16}$-inch by 3-inch by $3\frac{1}{2}$-inch angle rafters clipped to the tank shell and supported by one 4-inch center-pipe column.

Testing.—The bottom of each tank shall be tested with 4 inches of water as soon as the first ring is completed, before dropping from horses. Upon the completion of the shell, the tank shall be again tested full of water and caulked tight.

Twelve Run-down Tanks—500 Barrels

Dimensions.—Tanks shall be of vertical type with tight steel roofs, 20 feet diameter by 10 feet, $2\frac{3}{4}$ inches high.

Material.—All plate, rivets, and angles used in fabrication shall be of the best quality.

General construction.—Tanks shall be constructed throughout of mild open-hearth tank steel. Shell plates shall be joined to the bottom plates by means of an

angle ring turned inside of the shell, to which both the shell and the bottom shall be riveted. The upper course of the shell shall be reinforced with an angle ring turned out, unless otherwise specified, to which the roof sheet shall be attached. Plates and angles shall be of the following weights and sizes:

Bottom rectangles.........7.65 pounds	Second ring.............7.65 pounds
Bottom sketches...........7.65 pounds	Roof plates.............5.10 pounds
First ring.................7.65 pounds	Top angle.....$\frac{1}{4}$-inch by $2\frac{1}{2}$-in. by $2\frac{1}{2}$ in.
Bottom angle, $\frac{1}{4}$-inch by $2\frac{1}{2}$-in. by $2\frac{1}{2}$-in.	

Riveting.—All the riveting shall conform to the following schedule: all seams with the exception of roof plates shall be single riveted with $\frac{7}{16}$-inch rivets, $1\frac{1}{2}$-inch pitch; the latter to be riveted with $\frac{5}{8}$-inch rivets 2-inch pitch.

Shearing and caulking.—Bottom plates shall be caulked on inside, shell outside, roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 3-inch pumping-out flange, long hub, located in the shell, centered on a line 18 inches above bottom of tank and 2 feet to right of manhole.

1 3-inch run-down flange, single hub, located in the shell, centered on a line 9 inches below top and 90° to right of 4-inch pumping-out flange.

1 2-inch water draw-off flange, long hub, located in the shell, centered on a line 8 inches above bottom of tank and 2 feet to right of 3-inch pumping-out flange.

1 2-inch steam fire flange, single hub, located in the shell, centered on a line 9 inches below top 4 feet to right of 3-inch pumping-out flange.

Manholes.—Tanks shall be provided with two manholes; one 20-inch C. I. manhole in center of first ring, the latter reinforced by a $\frac{5}{16}$-inch by 40-inch by 40-inch plate at point of attachment; and one 20-inch steel plate neck located at the roof of the tank as close to the shell as good practice will allow and centered 3 feet to left of the side neck. The angle ring of the lower neck shall be faced true, as shall also the cast-iron cover plate for a corresponding distance. The top of the neck shall be provided with a light hinged cover which closes gas-tight.

Swing pipe.—The tanks shall be furnished with one 4-inch swing pipe, complete with a wire cable and single windlass. The windlass box shall be located on the roof and provided with a stuffing box for crank shafts and a gas-tight cover.

Ladder.—Each tank shall be provided with a standard steel ladder on the outside located 3 feet to the left of the lower manhole.

Roof supports.—The roof of each tank shall be laid on by $12\frac{5}{16}$-inch by $2\frac{1}{2}$-inch by $3\frac{1}{2}$-inch angle rafters clipped to the tank shell, and supported by one 4-inch center pipe column.

Testing.—The bottom of each tank shall be tested with 4 inches of water as soon as the first ring is completed. It shall be caulked tight in the presence of the purchaser before dropping from horses. Upon the completion of the shell, the tank shall be again tested full of water and caulked tight.

Four Bleachers—400 Barrels

Dimensions.—Bleachers shall be of vertical type with tight steel roof, 20 feet in diameter by 8 feet high.

Material.—All plate, rivets, and angles used in fabrication shall be made of the best quality.

General construction.—Tanks shall be constructed throughout of mild open-hearth tank steel. The shell plates shall be joined to the bottom plates by means of an angle ring turned inside of the shell, to which both shell and bottom shall be riveted. The upper course of the shell shall be reinforced with an angle ring turned out, unless otherwise specified to which the roof sheets shall be attached. Plates and angles shall be of the following weights and sizes;

Bottom rectangles..........7.65 pounds
Bottom sketches............7.65 pounds
First ring.................7.65 pounds
Bottom angle, ¼-inch by 2½-inch by 2½-inch
Second ring............7.65 pounds
Roof plates.............5.10 pounds
Top angle, ¼-inch by 2½-inch by 2½-inch

Riveting.—All riveting shall conform to the following schedule; all seams with the exception of roof plates, shall be single riveted with 7/16-inch rivets, 1½-inch pitch, the latter to be riveted with, ⅜-inch rivets, 2-inch pitch.

Shearing and caulking.—Bottom plates shall be caulked on the inside, shell outside, roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 3-inch pumping-out flange, long hub, located in the shell, centered on a line 18 inches above bottom of tank and 2 feet to right manhole.
1 4-inch drop-out flange, single hub, located in the shell, centered on a line 10 inches below top and 90° to right of 3-inch pumping-out flange.
1 2-inch water draw-off flange, long hub, located in the shell, centered on a line 8 inches above bottom of tank and 2 feet to right of 3-inch pumping-out flange.
1 2-inch steam fire flange, single hub, located in the shell, centered on a line 9 inches below top 4 feet to right of 3-inch pumping-out flange.

Manholes.—Tanks shall be provided with two manholes; one 20-inch C. I. manhole in the center of the first ring, the latter reinforced by a 5/16-inch by 40-inch by 40-inch plate at the point of attachment; and one 20-inch steel plate neck, located at the roof of the tank as close to the shell as good practice will allow and centered 3 feet to the left of the side neck. The angle ring of the lower neck shall be faced true, also cast-iron cover plate for a corresponding distance; top neck to be provided with a light hinged cover, closing gas-tight.

Hatches.—Bleachers shall each be provided with four 18-inch by 36-inch hatches, fitted with self-closing gas-tight doors, and shall be centered with long axes on radial lines, each hatch 6 feet from the apex of the roof cone, spaced 90° apart.

Swing pipe.—Tanks shall be furnished with one 4-inch swing pipe, complete with wire cable and single windlass. The windlass box shall be located on the roof and provided with a stuffing box for crank shafts and a gas-tight cover.

Ladder.—Each tank shall be provided with a standard steel ladder on the outside, located 3 feet to the left of the lower manhole.

Roof supports.—The roof of each tank shall be laid on by 12 5/16-inch by 2½-inch by 3½-inch angle rafters clipped to the tank shell and supported by one 4-inch center pipe column.

Testing.—The bottom of each tank shall be tested with 4 inches of water as soon as the first ring is completed, and shall be caulked tight before dropping from horses. Upon the completion of the shell, the tank shall be again tested full of water and caulked tight.

One Acid Tank—160 Barrels

Dimensions.—The tank shall be of vertical type, tight steel roof, 10 feet diameter by 10 feet high.

Material.—All plate, rivets, and angles used in fabrication shall be of the best quality.

General construction.—The tank shall be constructed throughout of mild open-hearth tank steel. The shell plates shall be joined to the bottom plates by means of an angle ring turned inside of the shell, to which both shell and bottom shall be riveted. The upper course of the shell shall be reinforced with an angle ring turned out to which the roof sheets shall be attached. The plates and angles shall be of the following weights and sizes:

Bottom rectangles.........10.20 pounds	Second ring.............8.92 pounds
Bottom sketches..........10.20 pounds	Roof plates.............7.65 pounds
First ring................10.20 pounds	Top angle...$\frac{5}{16}$-inch by $2\frac{1}{2}$-in. by $2\frac{1}{2}$-in.
Bottom angle, $\frac{3}{8}$-inch by $3\frac{1}{2}$-in. by $3\frac{1}{2}$-in.	

Riveting.—All of the riveting shall be done in accordance with the best acknowledged standard practice and conform to the following schedule:

Bottom plates	Riveting bottom seams
Rectangles....	$\frac{5}{8}$-inch R., 2-inch P., S. R. L.
Sketches......	$\frac{5}{8}$-inch R., 2-inch P., S. R. L.

Bottom Angle	Riveting bottom angle
To bottom....	$\frac{5}{8}$-inch R., 2-inch P., S. R. L.
To shell.......	$\frac{5}{8}$-inch R., 2-inch P., S. R. L.

Rings	Riveting circular seams	Riveting vertical seams
1 to 2........	$\frac{5}{8}$-inch R., 2-inch P., S. R. L.	$\frac{5}{8}$-inch R., $2\frac{1}{4}$-inch P., D. R. L.
2............	....	$\frac{7}{16}$-inch R., $1\frac{3}{4}$-inch P., S. R. L.

Top angle	Riveting top angle
To shell.......	$\frac{7}{16}$-inch R. $2\frac{1}{4}$-inch P., S. R. L.

Roof plates	Riveting roof plates
To top angle...	$\frac{7}{16}$-inch R., $2\frac{1}{4}$-inch P., S. R. L.
Plates........	$\frac{3}{8}$-inch R., 2-inch P., S. R. L.

Shearing and caulking.—Bottom plates shall be caulked inside, shell seams outside. Roof seams outside shall be lightly caulked.

Flanges.—Each tank shall be provided with the following flanges, latter to be of standard forged steel of the type known as boiler flanges, except the outlet flange, which shall be of special design and have its bottom face turned to seat a 60° conical plug.

1 2-inch inlet flange, single hub, located in the shell, centered on a line 9 inches below top and 2 feet to right of 2-inch outlet flange.

1 2-inch outlet flange, single hub, located in the bottom of tank, outside, 2 feet to right of lower manneck and as close to shell as good practice will allow.

Outlet plug.—The tank shall be equipped with 2-inch 60° conical C. I. lead covered outlet plug, operating in a special outlet flange; plug to be attached to a rod

passing through a guiding strap on the inside shell of the tank; stuffing box on the roof. It shall be raised or lowered from any desired level by a pull handle of convenient length through the agency of a simple lever device.

Manholes.—The tank shall be provided with two manholes; one 20-inch C. I. manhole in the center of the first ring, the latter reinforced by a $\frac{5}{16}$-inch by 40-inch by 40-inch plate at the point of attachment; and one 20-inch steel-plate neck, located in the roof of the tank as close to the shell as good practice will allow, centered 3 feet to the left of the side neck. The angle ring of lower neck shall be faced true, also the cast-iron cover plate, for a corresponding distance. The top neck shall be provided with a light hinged cover, with edges flanged-over, closing gas-tight.

Ladder.—Tank shall be provided with standard steel ladder on the outside located 3 feet to left of the lower manhole.

One Acid Blow Case

Dimensions.—The case shall be of horizontal type 3 feet in diameter by 4 feet long.

Material.—All plate and rivets used in fabrication shall be of the best quality.

General construction.—The shell of the case shall be made of one course of ½-inch or 20.4-pounds soft open-hearth tank steel. Heads shall be made from one plate each of ½-inch or 20.4-pounds flange steel, one plate to be flanged O. D., and the other I. D. with extra long and flattened flanging, so that corrosive action of acid around rivets will be reduced to a minimum.

Riveting.—All seams are to be double riveted with ¾-inch rivets 2½-inch P.

Shearing and caulking.—I. D. head to be bevel-sheared. All seams shall be caulked on the outside.

Flanges.—The case shall be provided with the following flanges, to be made of standard forged steel of the type known as extra heavy boiler flanges.

- 1 2-inch draw-off flange, located O. D. end, as close to shell as good practice will allow.
- 1 2-inch inlet flange, located shell on a line parallel to long axis of case directly opposite drawing-off flange and centered 8 inches from O. D. end.
- 1 2-inch air flange, located on above line and centered 18 inches from O. D. end.
- 1 ¾-inch vent flange, located on above line and centered 28 inches from O. D. end.

Testing.—Tanks shall be tested under 200-pounds hydrostatic pressure.

Two Lye Tanks—500 Gallons

Dimensions.—Each tank shall be of open vertical type, 5 feet in diameter by 4 feet high.

Material.—All plate and rivets used in fabrication shall be of the best quality.

General construction.—The shell of each tank shall be made of one course of 7.65-pounds soft open-hearth tank steel, bottom to be made from one plate of similar weight material and flanged O.D. for joining to shell, latter to be reinforced at top with ¼-inch by 2½-inch by 2½-inch angle turned out.

Riveting.—All seams shall be single riveted with $\frac{7}{16}$-inch rivet 1½-inch P.

Caulking.—All seams shall be caulked on the outside.

Specifications for Steel-plate Work for a 6000-barrel Refinery Running to Flux and Lubricants

General Items

	Diameter, feet		Length, feet	Barrels
8 Crude stills	14	×	40	1000
2 Crude stills	11	×	40	600
10 Reducing stills	14	×	40	1000
2 Reducing stills	11	×	40	600
6 Steam stills	16	×	40	1500
6 Steam stills, towers	7	×	30 feet high	
4 Heat-exchanging stills	11	×	20 feet long	300
2 Filter wash stills	11	×	20 feet long	300

	Length, feet		Width, feet		Depth, feet	in.
2 Crude still condenser boxes	56	×	42	×	11	6
1 Crude still condenser box	42	×	22	×	11	6
2 Reducing still condenser boxes	56	×	42	×	11	6
1 Reducing still condenser box	42	×	22	×	11	6
1 Steam still condenser box	84	×	42	×	11	6
1 Wash still condenser box	21	×	14	×	5	0
10 Pumping-out pans	42	×	7	×	5	0
5 Flow tanks	40	×	10	×	5	0
1 Flow tank	69	×	8	×	6	0
2 Flow tanks	100	×	8	×	6	0

	Diameter, feet	in.		Height, feet	in.		Barrels
3 Refined oil agitators	25		×	36	5		2000
6 Lubricating oil agitators	18		×	31	0		600
20 Filters	8		×	20	0		190
2 Storage tanks	114	6	×	30	2¼		55000
2 Storage tanks	95	6	×	29	9		37500
5 Storage tanks	70	0	×	29	3		20000
16 Storage tanks	50	0	×	29	3		10000
4 Working tanks	35	0	×	30	0		5000
10 Working tanks	25	0	×	30	0		2500
6 Refined oil bleachers	43	0	×	10	0		2500
9 Lubricating oil bleachers	34	0	×	10	0		1600
32 Run-down tanks	34	0	×	10	0		1600
20 Filling tanks	11	0	×	40	0	long	600
2 Acid tanks	10	0	×	10	0	high	125
2 Acid blow cases	3	0	×	8	0	long	
2 Lye tanks	10	0	×	10 feet high			125
2 Working tanks	10	0	×	4 feet high			56
2 Working tanks	5	0	×	4 feet high			500 Gals.
2 High-pressure tanks	5	0	×	15		feet long	300 cu. ft.

All the above units shall be fabricated in accordance with the following schedules:

Material

Plate, rivets, angles, bars and forgings.—Manufacturers' Standard Specifications as adopted by the Association of American Steel Manufacturers will govern the quality of these items for the different grades used.

Iron castings.—All iron castings will be of good quality gray foundry iron, and shall be provided in all cases with caulking strip.

Steel castings.—All steel castings will also be of good grade, free from pipes or blowholes.

General Construction

Shearing.—The edges of all plates shall be properly and neatly rotary bevel-sheared or planed for caulking, in accordance with detailed instructions below.

Scarfing.—All laps or corners shall be properly and neatly scarfed and chipped where required.

Flanging.—All flanging and dishing shall be executed in a careful manner conforming to the best standard practice.

Punching.—All rivet holes shall be accurately laid out and punched. The diameter of the punch shall not be more than $\frac{1}{16}$-inch greater than the diameter of the rivet, nor the diameter of the die more than $\frac{1}{16}$-inch greater than the diameter of the punch; $\frac{1}{32}$-inch variation shall govern with rivets less than $\frac{1}{2}$-inch diameter. All holes shall be clean-cut and free from ragged or torn edges; only punches and dies sharp and in first-class condition to be used.

Rolling.—All plates and angles shall be rolled carefully and true to required radius.

Fitting.—Before shipment of all knocked down material, the same shall be carefully fitted in shop and adjustments made where necessary.

Riveting.—Riveting shall be performed by pressure, or pneumatic tools in the shop, and by pneumatic tools or by hand in the field at the discretion of the erecting foreman. It shall be understood that all rivets over $\frac{1}{2}$-inch diameter shall be driven hot, sizes $\frac{7}{16}$-inch or $\frac{1}{2}$-inch hot or cold, sizes $\frac{3}{8}$-inch or under, cold. Rivet heads shall be concentric with the shank of the rivet within at least $\frac{1}{8}$ of an inch, but shall not be rejected because the rivet head shows lips caused by an excess of metal having been used in making the head over that required by the die.

Workmanship.—Workmanship shall be first-class in every respect.

Erection.—With the exception of items hereafter designated, all material shall be shipped knocked down and erected in the field on foundations prepared by the purchaser. The erecting foreman shall unload all such material from cars, but the purchaser will be required to handle same to erection points.

Testing.—When fabricated in the shop, units shall be tested under hydrostatic pressure required, and be made absolutely water-tight. For field erection, in addition to the final test, an intermediate inspection for the tightness of the bottom and the bottom angle shall be made on all items supported by false work or horses, before lowering to the final foundation. Such a test shall be made by filling the unit to be inspected with 4 inches of water, as soon as the first ring or lower side sheets are in position. All leaks shall be caulked tight. Upon completion, a final test will be given under the hydrostatic head specified, and all seepage seams showing shall be caulked tight.

Eight Crude Stills—1000 Barrels

Referring again to the general rules of construction previously given, especial attention is called to the following specifications.

1. **Manheads.**—Each still shall be equipped with two 20-inch quick-opening cast

iron manheads, complete with cover, crossbar, and screw; seat casting to be grooved for lime packing and cover provided with corresponding projecting annular ring. Manheads shall be located on the top of the shell on the center line between the lugs, each to be centered 4 feet from front and rear ends respectively.

2. **Mannecks.**—Each still shall be provided with two 20-inch plate mannecks, one on each end of the still, centered 2 feet 6 inches from the bottom. The necks shall be so constructed that their axes will be parallel to the long axis of the still; in other words, horizontal. The same shall have a bolt flange beaten out of one piece of ½-inch plate, rather than made from an angle ring, and shall finish ⅜-inch after facing. The manplate shall be of $\frac{7}{16}$-inch material, and faced-in to a distance from the edge equivalent to the facing of the flange. It shall be further provided with a crane support to hold the plate when not in use. Plates shall be secured by 28 ¾-inch square-shouldered steel bolts, the shoulders fitting in square holes cut in the flange neck.

3. **Tar plug.**—Each still shall be equipped with a 4-inch conical tar plug which shall operate in the usual way, and shall not exceed 20 pounds in weight, exclusive of the rods.

Dimensions.—Stills shall be of horizontal type, 14 feet in diameter by 40 feet long in the shell.

Shell.—The bottom of each still shall be made in two pieces of 20.4-pound plate, of the best quality of still bottom steel 111½ inches wide, running the full length of the still. The side sheets shall also be made in two pieces (each side) of 20.4-pound plate, best quality of still bottom steel, 76 inches wide, running the full length of the still. The lug sheets shall be in three pieces (each side) of the same width and weight of metal, but of the best quality of flange steel. The top or crown sheets are to be made of five roundabout courses of ⅜-inch or 15.3-pound tank steel.

Heads.—Heads shall be made from two pieces of 20.4-pound plate of the best quality of flange steel formed in conical shape, and flanged-in for a single row of ⅞-inch rivets.

Dome.—Each still shall be provided with a dome 48 inches in diameter by 48 inches high, and constructed of ⅜-inch or 15.3-pound flange steel. The shell and head of the dome shall each be formed from one piece of plate, the head to be standard O. D. and flanged-in, the dome to be centered at the top of the shell, on a line midway between lugs, 12 feet from the rear end of the still.

Lugs.—Each still shall be supported by means of sixteen C. I., pressed steel lugs, eight on each side of the still, the plane through the base of the lugs to pass through the longitudinal center axis of the still.

Riveting.—All horizontal and circular seams in bottom, side and lug plates, and also the seams in the heads, are to be double riveted with ⅞-inch rivets, 3¼-inch centers. All the seams in the shell, except as noted, shall be single riveted with ¾-inch rivets, on 3-inch centers. All the dome seams shall be single riveted with ¾-inch rivets, on 2¼-inch centers, lugs to shell with ⅞-inch rivets on 3¼-inch centers.

Caulking.—All the seams below the lugs, and the circular seams to the top of the lug sheets shall be caulked inside and outside; all other seams on outside only.

Flanges.—The following sizes shall be furnished:

All Stills

1 14-inch vapor flange, single hub, located in shell of dome, center of right-hand side, right and left side to be determined when facing rear end of still.

1 8-inch safety valve flange, single hub, located in shell of dome, center of left-hand side.

1 6-inch charging flange, long hub, located in top of shell, on center line between lugs, 17 feet from rear end.

1 2-inch steam flange, long hub, located in top of shell, on center line between lugs, 19 feet from rear end.

1 2-inch fire steam flange, single hub, located in top of shell, on center line between lugs, 20 feet from rear end.

2 1¼-foot tell-tale flanges, single hub, located in rear head of still, one centered 2 feet to right of perpendicular line through center of rear head, at a height 1 foot above bottom of still; and one directly above on a line 2 feet from top of still.

1 4-inch tar plug flange, single hub, located in bottom of shell, on center line between lugs, 9 feet from rear end.

Three Stills

2 8-inch flow flanges, long hub, located in rear head of still centered 8 feet apart equidistant from center of end, and on a horizontal line 5 feet above bottom of still.

Five Stills

2 6-inch flow flanges, long hub, located in rear head of still centered 8 feet apart equidistant from center of end, and on a horizontal line 5 feet above bottom of still.

Charging cock taps.—

No. 1 tap, rear head on center perpendicular line 35 inches below top of still.
No. 2 tap, 3 inches to right of center, 39 inches below top of still.
No. 3 tap, 3 inches to right of No. 2 tap, 42 inches below top of still.
No. 4 tap, 3 inches to right of No. 3 tap, 45 inches below top of still.

NOTE.—All taps shall be for ½-inch pipe.

Two Crude Stills—600 Barrels

Dimensions.—Stills shall be of horizontal type 11 feet in diameter by 40 feet long in the shell.

Shell.—The bottom of each still shall be made in two pieces of 20.4-pound plate, of the best quality of still bottom steel, 111½ inches wide, running the full length of the still. The lug sheets shall be made in two pieces (each side) of 17.85-pound plate best quality of flange steel, 76 inches wide, running the full length of the still. The top or crown sheets shall be of five roundabout courses of ⅜-inch or 15.3-pound tank steel.

Heads.—Heads shall be made in two pieces 20.4-pound plate of the best quality of flange steel, formed in conical shape, and flanged-in for a single row of ⅞-inch rivets.

Dome.—Each still shall be provided with a dome 40 inches in diameter by 40 inches high, to be constructed of ⅜-inch or 15.3-pound flange steel. The shell and head of the dome shall each be formed from one piece of plate. The head shall be standard O. D., and flanged-in; the dome shall be centered at top of the shell on a line midway between the lugs, 12 feet from the rear end of the still.

Lugs.—Each still shall be supported by means of sixteen C. I., or pressed-steel lugs, eight on each side of the still, plane through base of lugs to pass through longitudinal center axis of still.

Riveting.—All horizontal and circular seams in bottom, and lug plates, and also seam in the heads, shall be double riveted with ⅞-inch rivets 3¼-inch centers. All other seams in the shell, except as noted, shall be single riveted with ¾-inch rivets on 3-inch centers. All dome seams shall be single riveted with ¾-inch rivets on 2¼-inch centers; lugs to still with 1-inch rivets on 3½-inch centers.

Caulking.—All the seams below the lugs, and the circular seams to the top of the lug sheets shall be caulked inside and outside, all other seams on the outside only.

Flanges.—The following sizes shall be furnished:

Each Still

1 12-inch vapor flange, single hub, located in shell of dome, center of right-hand side, right and left side to be determined when facing rear end of still.

1 6-inch safety valve flange, single hub, located in shell of dome, center of left-hand side.

1 6-inch charging flange, long hub, located in top of shell, on center line between lugs, 17 feet from rear end.

1 2-inch steam flange, long hub, located in top of shell, on center line between lugs, 19 feet from rear end.

1 2-inch fire steam flange, single hub, located in top of shell, on center line between lugs, 20 feet from rear end.

2 1½-inch tell-tale flanges, single hub, located in rear head of still, one centered 2 feet to right of perpendicular line through center of rear head, at a height of 1 foot above bottom of still; and one directly above on a line 2 feet from top of still.

1 4-inch tar plug flange, single hub, located in bottom of shell, on center line between lugs, 9 feet from rear end.

2 4-inch flow flanges, long hub, located in rear head of still, centered 4 feet apart, equidistant from center of end, and on a horizontal line 4 feet from bottom of still.

Charging cock taps.—

No. 1 tap, rear head on center perpendicular line 30 inches below top of still.
No. 2 tap, 3 inches to right of center, 33 inches below top of still.
No. 3 tap, 3 inches to right of No. 2 tap, 36 inches below top of still.
No. 4 tap, 3 inches to right of No. 3 tap, 39 inches below top of still.

NOTE: All taps shall be for ½-inch pipe.

Ten Reducing Stills—1000 Barrels

Dimensions.—Stills shall be of horizontal type, 14 feet in diameter by 40 feet long in the shell.

Shell.—The bottom of each still shall be made in two pieces of 17.85-pound plate, best quality still bottom steel 111½ inches wide, running the full length of the still. The side sheets shall also be made in two pieces (each side) of 17.85-pound, best quality of still bottom steel, 76 inches wide, running the full length of the still. The lug sheets shall be in three pieces (each side) of same width and of 20.4-pound weight of metal, but of the best quality of flange steel. The top or crown sheets shall be made of five roundabout courses of ⅜-inch or 15.3-pound tank steel.

Heads.—Heads shall be made from two pieces of 20.4-pound plate best quality flange steel formed in conical shape, and flanged-in for a single row of ⅞-inch rivets.

Dome.—Each still will be provided with a dome 48 inches in diameter by 48 inches high, to be constructed of ⅜-inch or 15.3-pound flange steel. The shell and head of dome shall each be formed from one piece of plate, head to be standard O. D. and flanged-in; dome to be centered top of shell, on line midway between lugs, 12 feet from rear end of still.

Lugs.—Each still will be supported by means of twelve forged steel hanger traps, six on each side of still, eyes lying in a horizontal line 2 feet above center of still.

Rings	Riveting circular seams	Riveting vertical seams
1 to 2 .... 2 to 3	$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.	$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.

Top angle	Riveting top angle
To shell	$\frac{7}{16}$-inch R., $2\frac{1}{4}$-inch P., S.R.L.

Roof plates	Riveting roof plates
To top angle ...	$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.
Plates	$\frac{3}{4}$-inch R., 2 -inch P., S.R.L.

Shearing and caulking.—All the plates shall be properly and neatly bevel-sheared for caulking, angles excepted, bottom plates on inside, shell outside, roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 4-inch pumping-out flange, long hub, located shell, centered on a line 18 inches above bottom of tank and 2 feet to right of manhole.
1 3-inch pumping-in flange, single hub, located shell, centered on a line 9 inches below top and 2 feet to right of 4-inch pumping-in flange.
1 3-inch water draw-off flange, single hub, located shell, centered on a line 8 inches above bottom of tank and 4 feet to right of 4-inch pumping-out flange.
1 2-inch steam fire flange, single hub, located shell, centered on a line 9 inches below top and 4 feet to right of 3-inch pumping-in flange.

Manholes.—Tanks shall be provided with two manholes; one 20-inch C. I. manhole in the center of the first ring, the latter to be reinforced by a $\frac{5}{16}$-inch by 40-inch by 40-inch plate at the point of attachment; one 20-inch steel plate neck, located at the roof of the tank as close to the shell as good practice will allow and centered 3 feet to the left of the side neck. The angle ring of the lower neck and the cast-iron cover plate shall both be faced true, for a corresponding distance; top neck to be provided with a light hinged cover, closing gas-tight. Special gaging nipples, gas vent pipes, or foamite connections will be installed on a cost-plus basis as requested by purchaser.

Swing pipe.—Tanks shall be furnished with one 4-inch swing pipe, complete with wire cable and single windlass. The windlass box shall be located on the roof and provided with a stuffing box for the crank shaft and also a gas-tight cover.

Ladder.—Each tank shall be provided with a standard steel ladder on the outside, located 3 feet to the left of the lower manhole.

Roof supports.—The roof of each tank shall be laid on by $12\frac{5}{16}$-inch by 3-inch by $3\frac{1}{2}$-inch angle rafters clipped to the tank shell and supported by one 4-inch center-pipe column.

Testing.—The bottom of each tank shall be tested with 4 inches of water as soon as the first ring is completed, before dropping from horses. Upon the completion of the shell, the tank shall be again tested full of water and caulked tight.

Twelve Run-down Tanks—500 Barrels

Dimensions.—Tanks shall be of vertical type with tight steel roofs, 20 feet diameter by 10 feet, $2\frac{3}{4}$ inches high.

Material.—All plate, rivets, and angles used in fabrication shall be of the best quality.

General construction.—Tanks shall be constructed throughout of mild open-hearth tank steel. Shell plates shall be joined to the bottom plates by means of an

angle ring turned inside of the shell, to which both the shell and the bottom shall be riveted. The upper course of the shell shall be reinforced with an angle ring turned out, unless otherwise specified, to which the roof sheet shall be attached. Plates and angles shall be of the following weights and sizes:

Bottom rectangles.........7.65 pounds
Bottom sketches...........7.65 pounds
First ring.................7.65 pounds
Bottom angle, ¼-inch by 2½-in. by 2½-in.
Second ring.............7.65 pounds
Roof plates..............5.10 pounds
Top angle.....¼-inch by 2½-in. by 2½ in.

Riveting.—All the riveting shall conform to the following schedule: all seams with the exception of roof plates shall be single riveted with $\frac{7}{16}$-inch rivets, 1½-inch pitch; the latter to be riveted with ⅜-inch rivets 2-inch pitch.

Shearing and caulking.—Bottom plates shall be caulked on inside, shell outside, roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 3-inch pumping-out flange, long hub, located in the shell, centered on a line 18 inches above bottom of tank and 2 feet to right of manhole.
1 3-inch run-down flange, single hub, located in the shell, centered on a line 9 inches below top and 90° to right of 4-inch pumping-out flange.
1 2-inch water draw-off flange, long hub, located in the shell, centered on a line 8 inches above bottom of tank and 2 feet to right of 3-inch pumping-out flange.
1 2-inch steam fire flange, single hub, located in the shell, centered on a line 9 inches below top 4 feet to right of 3-inch pumping-out flange.

Manholes.—Tanks shall be provided with two manholes; one 20-inch C. I. manhole in center of first ring, the latter reinforced by a $\frac{5}{16}$-inch by 40-inch by 40-inch plate at point of attachment; and one 20-inch steel plate neck located at the roof of the tank as close to the shell as good practice will allow and centered 3 feet to left of the side neck. The angle ring of the lower neck shall be faced true, as shall also the cast-iron cover plate for a corresponding distance. The top of the neck shall be provided with a light hinged cover which closes gas-tight.

Swing pipe.—The tanks shall be furnished with one 4-inch swing pipe, complete with a wire cable and single windlass. The windlass box shall be located on the roof and provided with a stuffing box for crank shafts and a gas-tight cover.

Ladder.—Each tank shall be provided with a standard steel ladder on the outside located 3 feet to the left of the lower manhole.

Roof supports.—The roof of each tank shall be laid on by 12$\frac{5}{16}$-inch by 2½-inch by 3½-inch angle rafters clipped to the tank shell, and supported by one 4-inch center pipe column.

Testing.—The bottom of each tank shall be tested with 4 inches of water as soon as the first ring is completed. It shall be caulked tight in the presence of the purchaser before dropping from horses. Upon the completion of the shell, the tank shall be again tested full of water and caulked tight.

Four Bleachers—400 Barrels

Dimensions.—Bleachers shall be of vertical type with tight steel roof, 20 feet in diameter by 8 feet high.

Material.—All plate, rivets, and angles used in fabrication shall be made of the best quality.

General construction.—Tanks shall be constructed throughout of mild open-hearth tank steel. The shell plates shall be joined to the bottom plates by means of an angle ring turned inside of the shell, to which both shell and bottom shall be riveted. The upper course of the shell shall be reinforced with an angle ring turned out, unless otherwise specified to which the roof sheets shall be attached. Plates and angles shall be of the following weights and sizes:

Bottom rectangles..........7.65 pounds	Second ring............7.65 pounds
Bottom sketches............7.65 pounds	Roof plates.............5.10 pounds
First ring.................7.65 pounds	Top angle, ¼-inch by 2½-inch by 2½-inch
Bottom angle, ¼-inch by 2½-inch by 2½-inch	

Riveting.—All riveting shall conform to the following schedule; all seams with the exception of roof plates, shall be single riveted with $\frac{7}{16}$-inch rivets, 1½-inch pitch, the latter to be riveted with, ⅜-inch rivets, 2-inch pitch.

Shearing and caulking.—Bottom plates shall be caulked on the inside, shell outside, roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 3-inch pumping-out flange, long hub, located in the shell, centered on a line 18 inches above bottom of tank and 2 feet to right manhole.

1 4-inch drop-out flange, single hub, located in the shell, centered on a line 10 inches below top and 90° to right of 3-inch pumping-out flange.

1 2-inch water draw-off flange, long hub, located in the shell, centered on a line 8 inches above bottom of tank and 2 feet to right of 3-inch pumping-out flange.

1 2-inch steam fire flange, single hub, located in the shell, centered on a line 9 inches below top 4 feet to right of 3-inch pumping-out flange.

Manholes.—Tanks shall be provided with two manholes; one 20-inch C. I. manhole in the center of the first ring, the latter reinforced by a $\frac{5}{16}$-inch by 40-inch by 40-inch plate at the point of attachment; and one 20-inch steel plate neck, located at the roof of the tank as close to the shell as good practice will allow and centered 3 feet to the left of the side neck. The angle ring of the lower neck shall be faced true, also cast-iron cover plate for a corresponding distance; top neck to be provided with a light hinged cover, closing gas-tight.

Hatches.—Bleachers shall each be provided with four 18-inch by 36-inch hatches, fitted with self-closing gas-tight doors, and shall be centered with long axes on radial lines, each hatch 6 feet from the apex of the roof cone, spaced 90° apart.

Swing pipe.—Tanks shall be furnished with one 4-inch swing pipe, complete with wire cable and single windlass. The windlass box shall be located on the roof and provided with a stuffing box for crank shafts and a gas-tight cover.

Ladder.—Each tank shall be provided with a standard steel ladder on the outside, located 3 feet to the left of the lower manhole.

Roof supports.—The roof of each tank shall be laid on by $12\frac{5}{16}$-inch by 2½-inch by 3½-inch angle rafters clipped to the tank shell and supported by one 4-inch center pipe column.

Testing.—The bottom of each tank shall be tested with 4 inches of water as soon as the first ring is completed, and shall be caulked tight before dropping from horses. Upon the completion of the shell, the tank shall be again tested full of water and caulked tight.

One Acid Tank—150 Barrels

Dimensions.—The tank shall be of vertical type, tight steel roof, 10 feet diameter by 10 feet high.

Material.—All plate, rivets, and angles used in fabrication shall be of the best quality.

General construction.—The tank shall be constructed throughout of mild open-hearth tank steel. The shell plates shall be joined to the bottom plates by means of an angle ring turned inside of the shell, to which both shell and bottom shall be riveted. The upper course of the shell shall be reinforced with an angle ring turned out to which the roof sheets shall be attached. The plates and angles shall be of the following weights and sizes:

Bottom rectangles.........10.20 pounds	Second ring.............8.92 pounds
Bottom sketches...........10.20 pounds	Roof plates.............7.65 pounds
First ring................10.20 pounds	Top angle...5/16-inch by 2½-in. by 2½-in.
Bottom angle, ⅜-inch by 3½-in. by 3½-in.	

Riveting.—All of the riveting shall be done in accordance with the best acknowledged standard practice and conform to the following schedule:

Bottom plates	Riveting bottom seams	
Rectangles....	⅝-inch R., 2-inch P., S. R. L.	
Sketches......	⅝-inch R., 2-inch P., S. R. L.	
Bottom Angle	**Riveting bottom angle**	
To bottom....	⅝-inch R., 2-inch P., S. R. L.	
To shell.......	⅝-inch R., 2-inch P., S. R. L.	
Rings	**Riveting circular seams**	**Riveting vertical seams**
1 to 2........	⅝-inch R., 2-inch P., S. R. L.	⅝-inch R., 2¼-inch P., D. R. L.
2..............	....	7/16-inch R., 1¾-inch P., S. R. L.
Top angle	**Riveting top angle**	
To shell.......	7/16-inch R. 2¼-inch P., S. R. L.	
Roof plates	**Riveting roof plates**	
To top angle...	7/16-inch R., 2¼-inch P., S. R. L.	
Plates........	⅝-inch R., 2-inch P., S. R. L.	

Shearing and caulking.—Bottom plates shall be caulked inside, shell seams outside. Roof seams outside shall be lightly caulked.

Flanges.—Each tank shall be provided with the following flanges, latter to be of standard forged steel of the type known as boiler flanges, except the outlet flange, which shall be of special design and have its bottom face turned to seat a 60° conical plug.

1 2-inch inlet flange, single hub, located in the shell, centered on a line 9 inches below top and 2 feet to right of 2-inch outlet flange.

1 2-inch outlet flange, single hub, located in the bottom of tank, outside, 2 feet to right of lower manneck and as close to shell as good practice will allow.

Outlet plug.—The tank shall be equipped with 2-inch 60° conical C. I. lead covered outlet plug, operating in a special outlet flange; plug to be attached to a rod

Mannecks.—Each tower shall be provided with three 18-inch C. I. mannecks; one centered in top of tower; one in side of shell, centered 24 inches from bottom, on a line midway between two adjacent lugs at 90° to vapor inlet flange and one in side of shell, directly above second neck centered 15 feet above bottom. The necks shall have a bolt flange turned true, and the plates shall be faced in to a distance from edge equivalent to the facing of the flange. The side necks shall be provided with crane supports to hold the plates when not in use. All plates shall be secured by 22 ¾-inch standard bolts.

Gratings.—Each tower shall be provided with two sets of gratings or false bottoms, of 17.85 plate, to be respectively supported 4 feet and 17 feet above bottom, by ⅜-inch by 3-inch by 3-inch angle rings riveted around inside of shell, and by three angles of the same weight riveted across the shell. Grating plates shall be cut in strips sufficiently narrow to readily pass through mannecks, shall rest without fastening on supports, and be perforated with 4-inch holes on 5½-inch centers.

Testing.—Towers shall be erected at approximately 26 feet above grade, and upon completion shall be tested under 25-pounds hydrostatic pressure.

Four Heat-exchanging Stills

Dimensions.—Stills shall be of horizontal type, 11 feet in diameter by 20 feet long in the shell.

Shell.—Each still shall be made of three or four roundabout courses of 17.85-pound best quality tank steel.

Heads.—Heads shall be made in two pieces of 17.85-pound plate, best quality flange steel, formed in conical shape, and flanged-in for a double row of ¾-inch rivets.

Wells.—Each still shall be provided with a well 12 inches in diameter by 12 inches deep, to be constructed of ⅜-inch or 15.3-pound flanged steel, the shell and head of the well each to be formed from one piece of plate, head to be standard O. D. and flanged-in. The well shall be centered at the bottom of shell, 15 inches from rear end of still.

Riveting.—All seams shall be double riveted with ¾-inch rivets, on 3-inch centers.

Caulking.—All seams shall be caulked inside and outside.

Flanges.—The following sizes shall be furnished:

Each Still

1 8-inch vapor flange, single hub, located in top of shell, on line parallel to axis of still directly opposite similar lines passing through center of well, and 3 feet from rear end.

1 2-inch fire steam flange, single hub located in top of shell, on same line as vapor flange, 7 feet from rear end.

1 6-inch outlet flange, single hub, located in rear head of still, centered on a line 24 inches from top, and 24 inches to left of central perpendicular line passing through center of head and well.

1 3-inch inlet flange, long hub, located in rear head, centered on a line 24 inches from top, and 24 inches to right of central perpendicular line passing through center of head and well.

1 3-inch inlet flange, long hub, located in rear head, centered on a line 24 inches from top, and 36 inches to right of central perpendicular line passing through center of head and well.

1 6-inch inlet flange, single hub, located in front head, centered on a line 20 inches above bottom, 24 inches to left of central perpendicular line coinciding with similar line on rear head.

1 3-inch outlet flange, long hub, located in front head, centered on a line 20 inches above bottom, and 24 inches to right of central perpendicular line, coinciding with similar line on rear head.
1 3-inch outlet flange, long hub, located in front head, centered on a line 20 inches above bottom, and 36 inches to right of central perpendicular line, coinciding with similar line on rear head.
2 1¼-inch tell-tale flanges, single hub, located in rear head of still, one centered 3 feet left of central perpendicular line, at a height of 2 feet above bottom of still; and one directly above on a line 2 feet from top of still.
1 4-inch draw-off flange, single hub, located in center of well-head outside.

Mannecks.—Each still shall be provided with three 20-inch plate mannecks; one at the rear head of the still, centered on perpendicular line mentioned above, 24 inches above bottom; one at the front head of the still, centered on center perpendicular line mentioned above, 24 inches from bottom; and one located on same line 24 inches from top.

Testing.—Stills shall be tested under 25 pounds hydrostatic pressure.

Two Filter Wash Stills

Dimensions.—Stills shall be of horizontal type, 11 feet in diameter by 20 feet long in the shell.

Shell.—Each still shall be made of three or four roundabout courses of 15.3-pound best quality tank steel.

Heads.—Heads shall be made in two pieces of 17.85-pound plate, best quality flange steel, formed in conical shape, and flanged-in for a single row of ⅝-inch rivets.

Well.—Each still shall be provided with well 12 inches in diameter by 12 inches deep, to be constructed of ⅜-inch or 15.3-pound flanged steel, shell and head of well each to be formed from one piece of plate, head to be standard O. D. and flanged-in; well to be centered at bottom of shell, 15-inches from rear end of still.

Riveting.—All circular seams shall be single riveted with ¾-inch rivets on 2¼-inch centers; all horizontal seams to be double riveted with ¾-inch rivets on 3-inch centers. Horizontal seam in heads shall be double riveted, and circular seams single riveted with ⅝-inch rivets, on 3¼-inch and 2¼-inch centers respectively.

Caulking.—All seams shall be caulked inside and outside.

Flanges.—The following sizes shall be furnished:

Each Still

1 6-inch vapor flange, single hub, located at top of shell on line parallel to axis of still directly opposite similar line, passing through center of well; 3 feet from rear end.
1 3-inch steam flange, single hub located at top of shell, on same line as vapor flange, 7 feet from rear end.
1 2-inch fire steam flange, single hub, located at top of shell, on same line as vapor flange, centered 8 feet from rear end.
2 1¼-inch tell-tale flanges, single hub, located at rear head of still, one centered 2 feet to right of perpendicular line through center of rear head, at a height of 1 foot above bottom of still; and one directly above on a line 2 feet from top of still.
1 3-inch draw-off flange, single hub, located at center of well-head.

Manheads.—Each still shall be equipped with one 20-inch quick opening cast-iron manhead. The manhead shall be located on the top of the still, on same line as vapor flange, centered 2 feet 6 inches from front end.

Mannecks.—Each still shall be provided with one 20-inch plate manneck on front end of still, centered 2 feet 6 inches from bottom.

Two Crude Still Condenser Boxes

Dimensions.—Each condenser shall be rectangular in shape, open top type, 56 feet long by 42 feet wide by 11 feet 6 inches deep and shall be divided into six compartments by partitions parallel to the 42-foot side; compartments being 42 feet long, by 11 feet 6 inches deep.

The partitions shall be located as follows:

First	partition 11 feet from 42-foot end.
Second	partition 6 feet from 1st.
Third	partition 11 feet from 2d.
Fourth	partition 11 feet from 3d.
Fifth	partition 6 feet from 4th.
Sixth	partition 11 feet from 5th.

The two small compartments shall be further subdivided in halves by partitions parallel to long, 56-foot side, thus making in all four compartments 42 feet long by 11 feet wide by 11 feet 6 inches deep, and four compartments 21 feet long by 6 feet wide by 11 feet 6 inches deep.

General construction.—Each condenser shall be fabricated throughout of 12.75-pound plate, best grade tank or pressing steel. The 56-foot sides and bottom will be made up of eight courses of six plates each, sixteen plates forming main portion of bottom, and sixteen plates forming each side and remainder of bottom; the lower course of side plates being turned on a $\frac{3}{8}$-inch radius to form sides of condenser. The 42-foot ends and partitions shall be made of six single-plate courses, sides and bottom flanged-in to unite with long, 56-foot sides and bottom of condenser. The partitions forming the small compartments shall be made from two plates flanged-in on sides and bottom.

Angle bracing.—Each condenser shall be stiffened on the inside walls by a series of vertical angle units, $\frac{3}{8}$-inch by $3\frac{1}{2}$-inches by 5 inches riveted back to back on 5-inch flange, extending from top to bottom of condenser except as hereafter noted. These double-angle units shall be located every 6 feet on the 42-foot sides of box and partitions. except that all angle units on the right hand of such partitions shall be omitted entirely save a short 1-foot section at top for attaching tie rods. On the long 56-foot sides, a double angle stiffening unit shall be located in the center of each 11-foot compartment. The sides and partitions of the condenser shall be further reinforced by $\frac{3}{8}$-inch by 3-inch by 3-inch angles running completely around the top of the box and across the partition sheets. The joints shall be neatly butted and fastened with butt straps.

Cross rods.—Angle units shall be tied together with $1\frac{1}{2}$-inch rounds, fitted with clevises on each end and turnbuckle in center. The clevis pins shall be located 6 inches below the top of the condenser. Such construction affords six rows of tie rods 6 feet apart, parallel to 56-foot sides, extending from the ends of the box to the compartment walls, and from wall to wall across entire box; and four rows of tie rods parallel to 42-foot side, across middle of 42-foot by 11-foot compartments, connecting the long 56-foot sides.

Tower bridge.—Two rows of vertical angle stiffeners, adjacent to 56-foot front side of box shall extend 2 feet above top of condenser, including all units, both on 42-foot ends and cross partitions; thus making 7 extensions in each of the two front rows, or 14 in all. On top of these shall be laid and placed parallel to the long 56-foot

sides, two 9-inch 21-pound I-beams, one on each set of supports, running the full length of the box from end to end. These beams shall be riveted to the top of the extensions by angle plates and knee braces of appropriate design, forming a bridge for tower supports.

Riveting.—All seams shall be single riveted with $\frac{3}{8}$-inch rivets, on 2-inch centers; top angles and vertical stiffeners with $\frac{3}{8}$-inch rivets, on 6-inch centers.

Caulking.—Bottom of condenser and partitions shall be caulked on inside, sides on outside.

Flanges.—All flanges, except draw-off flanges, shall be of standard forged steel type known as tank flanges; draw-off flanges will be of medium heavy forged steel, turned on bottom face to set 50° conical plug. The following sizes shall be furnished for each condenser:

8 4-inch overflow flanges, long hub, located on long, 56-foot rear side, on a line 2-feet 6 inches below top of box, centered as follows:

First	flange 2 feet to left of right-hand end.
Second	flange 2 feet to left of first partition.
Third	flange 4 feet to left of first partition.
Fourth	flange 2 feet to left of second partition.
Fifth	flange 2 feet to left of third partition.
Sixth	flange 4 feet to left of fourth partition.
Seventh	flange 4 feet to left of fourth partition.
Eighth	flange 2 feet to left of fifth partition

2 4-inch overflow flanges, long hub, located on short, 6-foot partitions, rear side, on a line 2 feet 6 inches below top of box, centered as follows:

6 4-inch draw-off flanges, single hub, located on the bottom, on a line parallel to 56-foot side and 18 feet 6 inches from rear of condenser, centered as follows:

First	flange 1 foot to left of right-hand end.
Second	flange 1 foot to left of first partition.
Third	flange 1 foot to left of second partition.
Fourth	flange 1 foot to left of third partition.
Fifth	flange 1 foot to left of fourth partition.
Sixth	flange 1 foot to left of fifth partition.

2 4-inch draw-off flanges, single hub, located on the bottom, on a line parallel to 56-foot side and 23 feet 6 inches from rear of condenser, centered as follows:

First	flange 1 foot to left of first partition.
Second	flange 1 foot to left of fourth partition.

Draw-off plugs.—Each condenser compartment shall be equipped with a 4-inch conical draw-off plug operating in a special steel outlet flange. The plug shall be attached to a rod passing through the guiding strap on the inside vertical wall of the condenser, and through the angle bracket attached to top reinforcing angle. The rod shall project 3 feet above the top of the box and be provided with a T handle so it may be conveniently raised or lowered from the walkway as desired. The plug shall be turned at a slightly different angle than the outlet flange to avoid binding, or approximately at 50°, and shall not exceed 6 inches in height nor weigh over 20 pounds, exclusive of rod.

Walkway.—Each condenser shall be provided with a suitable walkway, supported on top, centered midway between 56-foot sides, and extending full length. Same shall be 4 feet 4 inches in breadth, and constructed of two 8-inch 11.25-pound channel

purlins, running the full length of the box, flanges turned out; purlins to be tied together at 8-foot intervals by two ¾-inch bolts centered 5 inches apart on a line at right angles to long axis of channel. Purlins shall be spaced 4 feet apart, distance to be maintained by 4-foot pipe spacers, through which tie bolts shall pass. On top of the purlin frame shall rest C. I. open checkerwork gratings, 4 feet 4 inches wide by 6 feet long, provided with projecting lugs on the under side, allowing easy insertion between purlins and affording readily removable treads. A suitable angle or pipe railing shall be furnished around all sides of the walkway save where approaches connect.

Testing.—Condenser shall be erected approximately 20 feet above grade, and upon completion shall be tested full of water by compartments and as a whole.

One Crude Still Condenser Box

Dimensions.—Condenser shall be rectangular in shape, open top type, 42 feet long by 22 feet wide by 11 feet 6 inches deep, and shall be divided into two equal compartments, 42 feet long by 11 feet wide by 11 feet 6 inches deep by a central partition parallel to 42-foot side.

General Construction.—Condenser shall be fabricated throughout of 12.75-pound plate, best grade tank or pressing steel. The 42-foot sides and bottom shall be made up of eight courses of three plates each, eight plates forming the bottom, and eight plates forming each side; bottom plates being turned on a ⅜-inch radius to form sides of condenser. The 22-foot ends shall be made of two single horizontal courses, sides and bottom flanged-in to unite with 42-foot sides and bottom of condenser. Central partition shall be made from eight single vertical courses turned on ⅜-inch radius at bottom, and flanged-in on sides.

Angle bracing.—Condenser shall be stiffened on the inside walls by a series of vertical angle units ⅜-inch by 3½ inches by 5 inches, riveted back to back on a 5-inch flange, extending top to bottom of condenser except as hereafter noted. These double angle units shall be located every 6 feet on the 42-foot sides of box and partition, except that all angle units on one side of partition shall be omitted entirely save a short 1-foot section at top for attaching tie rods. On the 22-foot ends, a double angle stiffening unit shall be located in the center of each 11-foot compartment. Sides and partition of condenser shall be further reinforced by ⅜-inch by 3 inch by 3-inch angles running completely around top of box and across partition sheet, joints to be neatly butted, and fastened with butt straps.

Cross rods.—Angle units shall be tied together with 1¼-inch rounds fitted with clevises on each end and turnbuckle in center. Clevis pins shall be located 6 inches below top of condenser; such construction affording six rows of tie rods 6 feet apart, parallel to 22-foot ends, extending from sides of box to compartment wall; and two rows of tie rods parallel to 42-foot side across middle of 42-foot by 11-foot compartments, connecting the 22-foot ends.

Tower bridge.—Two rows of vertical angle stiffeners, adjacent to 22-foot front ends of box shall extend 2 feet above the top of the condenser, including all units, both on 42-foot sides and central partition; thus making three extensions in each of the two front rows, or six in all. On top of these shall be laid and placed parallel to the 22-foot ends, two 9-inch 21-pound I-beams, one on each set of supports, running full width of box from side to side. These beams shall be riveted to top of extensions by angle plates and knee braces of appropriate design forming a bridge for tower supports.

Riveting.—All seams shall be single riveted with ⅜-inch rivets, on 2-inch centers; top angles and vertical stiffeners with ⅜-inch rivets, on 6-inch centers.

Caulking.—The bottom of the condenser and the partition shall be caulked on inside, sides on outside.

Flanges.—All flanges, except draw-off flanges, shall be of standard forged steel type known as tank flanges. Draw-off flanges shall be of medium heavy forged steel, turned on bottom face to seat 50° conical plug. The following sizes shall be furnished:

2 4-inch overflow flanges, long hub, located on 22-foot rear end, on a line 2 feet below top of box, centered as follows:

First flange 2 feet to left of right-hand side.
Second flange 2 feet to left of central partition.

2 4-inch draw-off flanges, single hub, located on the bottom, on a line parallel to 22-foot end and 18 feet 6 inches from rear of condenser centered as follows:

First flange 1 foot to left of right-hand side.
Second flange 1 foot to left of central partition.

Draw-off plugs.—The condenser compartment shall be equipped with a 4-inch conical draw-off plug operating in a special steel outlet flange. The plug shall be attached to a rod passing through a guiding strap on the inside vertical wall of condenser, and angle bracket attached to top reinforcing angle. The rod shall project 3 feet above the top of the box and be provided with a T handle so it may be conveniently raised or lowered from the walkway as desired. The plug shall be turned at a slightly different angle from the outlet flange to avoid binding, or approximately at 50°, and shall not exceed 6 inches in height, nor weigh over 20 pounds exclusive of rod.

Walkway.—Condenser shall be provided with a suitable walkway, supported on top, centered midway between 22-foot ends, and extending full width. Same shall be 4 feet 4 inches in breadth, and constructed of two 8-inch 11.25-pound channel purlins running full width of box, flanges turned out; purlins to be tied together at 8-foot intervals by two $\frac{3}{4}$-inch bolts centered 5 inches apart on a line at right angles to long axis of channel. Purlins shall be spaced 4 feet apart, distance to be maintained by 4-foot pipe spacers, through which tie bolts shall pass. On top of purlin frame shall rest C. I. open checkerwork gratings, 4 feet 4 inches wide by 6 feet long, provided with projecting lugs on underside, allowing easy insertion between purlins and affording readily removable treads. A suitable angle or pipe railing shall be furnished around all sides of walkway save where approaches connect.

Testing.—Condenser shall be erected approximately 20 feet above grade and upon completion shall be tested full of water by compartments and as a whole.

Two Reducing Still Condenser Boxes

Dimensions.—Each condenser shall be rectangular in shape, open top type, 56 feet long by 42 feet wide by 11 feet 6 inches deep, and shall be divided into four equal compartments by partitions parallel to the 42-foot side, the compartments then being 42 feet long by 14 feet wide by 11 feet 6 inches deep.

General construction.—Each condenser shall be fabricated throughout of 12.75-pound plate best grade tank or pressing steel. The 56-foot sides and bottom shall be made up of eight courses of six plates each, sixteen plates forming main portion of bottom, and sixteen plates forming each side and remainder of bottom, the lower course of side plates shall be turned on a $\frac{3}{8}$-inch radius to form the sides of the condenser. The 42-foot ends and partitions shall be made of six single plate courses, sides and bottom flanged-in to unite with long 56-foot sides and bottom of condenser.

Angle bracing.—Each condenser shall be stiffened on the inside walls by a series of vertical angle units $\frac{3}{8}$-inch by $3\frac{1}{2}$ inches by 5 inches, riveted back to back on a 5-inch flange, extending top to the bottom of the condenser except as hereafter noted.

These double angle units shall be located every 6 feet on the 42-foot sides of box and partitions, except that all angle units on the right-hand side of such partitions shall be omitted entirely save a short 1-foot section at top for attaching tie rods. On the long 56-foot sides, a double angle stiffening unit shall be located in the center of each 14-foot compartment. Sides and partitions of condenser shall be further reinforced by ⅜-inch by 3-inch by 3-inch angles running completely around top of box and across partition sheets, joints to be neatly butted, and fastened with butt straps.

Cross rods.—Angle units shall be tied together with 1⅛-inch rounds, fitted with clevises on each end and turnbuckle in center, clevis pins to be located 6 inches below top of condenser; such construction affording six rows of tie rods 6 feet apart, parallel to 56-foot sides, extending from ends of box to compartment walls, and from wall to wall across entire box; and four rows of tie rods parallel to 42-foot side across middle of 42-foot by 11-foot compartment connecting the long 56-foot sides.

Tower bridge.—Two rows of vertical angle stiffeners, adjacent to 56-foot front side of box shall extend 2 feet above top of condenser, including all units, on both 42-foot ends and cross partitions; thus making five extensions in each of the two front rows or ten in all. On top of these shall be laid and placed parallel to the long 56-foot sides, two 9-inch 21-pound I-beams, one on each set of supports, running the full length of the box from end to end. These beams shall be riveted to the top of the extensions by angle plates and knee braces of appropriate design forming a bridge for tower supports.

Riveting.—All seams shall be single with ⅜-inch rivets, on 2-inch centers, top angles and vertical stiffeners with ⅜-inch rivets, on 6-inch centers.

Caulking.—Bottom of condenser and partitions shall be caulked on inside, sides on outside.

Flanges.—All flanges, except draw-off flanges, shall be of standard forged steel type known as tank flanges. Draw-off flanges shall be of medium heavy forged steel, turned on bottom face to seat 50° conical plug. The following sizes shall be furnished for each condenser:

4 4-inch overflow flanges, long hub, located on long 56-foot rear side, on a line 2 feet 6 inches below top of box, centered as follows:

First flange 2 feet to left of right-hand end.
Second flange 2 feet to left of first partition.
Third flange 2 feet to left of second partition.
Fourth flange 2 feet to left of third partition.

4 4-inch draw-off flanges, single hub, located bottom, on a line parallel to 56-foot side and 23 feet 6 inches from rear of condenser, centered as follows:

First flange 1 foot to left of right-hand end.
Second flange 1 foot to left of first partition.
Third flange 1 foot to left of second partition.
Fourth flange 1 foot to left of third partition.

Draw-off plugs.—Each condenser compartment shall be equipped with a 4-inch conical draw-off plug operating in a special steel outlet flange. The plug shall be attached to a rod passing through a guiding strap on inside vertical wall of condenser, and through the angle bracket attached to top reinforcing angle. The rod shall project 3 feet above the top of the box and be provided with T handle so it may be conveniently raised or lowered from the walkway as desired. The plug shall be turned at a slightly different angle than the outlet flange to avoid binding, or approximately at 50°, and shall not exceed 6 inches in height, nor weigh over 20 pounds exclusive of rod.

Walkway.—Each condenser shall be provided with a suitable walkway, supported on top, centered midway between 56-foot sides, and extending full length. Same shall be 4 feet 4 inches in breadth, and constructed of two 8-inch 11.25-pound channel purlins, running the full length of box, flanges turned out. The purlins shall be tied together at 8-foot intervals by two ¾-inch bolts centered 5 inches apart on a line at right angles to long axis of channel. Purlins shall be spaced 4 feet apart, distance to be maintained by 4-foot pipe spacers, through which tie bolts shall pass. On top of the purlin frame shall rest C. I. open checkerwork gratings 4 feet 4 inches wide by 6 feet long, provided with projecting lugs on under side, allowing easy insertion between purlins and affording readily removable treads. A suitable angle or pipe railing shall be furnished around all sides of the walkway save where approaches connect.

Testing.—The condenser shall be erected approximately 20 feet above grade and upon completion shall be tested full of water by compartments and as a whole.

One Reducing Still Condenser Box

Specifications.—The condenser shall be similar to crude still condenser box in every particular.

One Steam Still Condenser Box

Dimensions.—The condenser shall be rectangular in shape, open-top type, 84 feet long by 42 feet wide by 11 feet 6 inches deep, and shall be divided into six equal compartments by partitions parallel to the 42-foot side, compartments then being 42 feet long by 14 feet wide by 11 feet 6 inches deep.

General construction.—The condenser shall be fabricated throughout of 12.75-pound plate, best grade of tank or pressing steel. The 84-foot sides and bottom shall be made up of twelve courses of six plates each, twenty-four plates forming main portion of bottom, and twenty-four plates forming each side and remainder of bottom, lower course of side plates being turned on a ⅜-inch radius to form sides of condenser. The 42-foot ends and partitions shall be made of six single vertical plate courses, sides and bottom flanged-in to unite with long 84-foot sides and bottom of condenser.

Angle bracing.—The condenser shall be stiffened on inside walls by a series of vertical angle units ⅜ inch by 3½ inches by 5 inches, riveted back to back on a 5-inch flange, extending top to bottom of condenser except as hereafter noted. These double angle units shall be located every 6 feet on the 42-foot sides of box and partitions, except that all angle units on the right-hand side of such partitions shall be omitted entirely save a short 1-foot section at top for attaching tie rods. On the long 84-foot sides, a double-angle stiffening unit shall be located in the center of each 14-foot compartment. Sides and partitions of condenser shall be further reinforced by ⅜-inch by 3-inch by 3-inch angles running completely around top of box and across partition sheets. Joints shall be neatly butted and fastened with butt straps.

Cross rods.—Angle units shall be tied together with 1¼-inch rounds, fitted with clevises at each end and turnbuckle in center, clevis pins to be located 6 inches below top of condenser. Such construction affords six rows of tie rods 6 feet apart, parallel to 84 foot sides, extending from ends of box to compartment walls and from wall to wall across entire box; and six rows of tie rods parallel to the 42-foot side across middle of 42 foot by 11 foot 6 inch compartment connecting the long 84-foot sides.

Tower bridge.—Two rows of vertical angle stiffeners, adjacent to 84-foot front side of box shall extend 2 feet above top of condenser, including all units, both on 42-foot ends and cross partitions, thus making seven extensions in each of the two front rows, or fourteen in all. On top of these shall be laid and placed parallel to the long 84-foot sides, two 9-inch 21-pound I-beams, one on each set of supports, running full length of box from end to end. These beams shall be riveted to the top of the extensions

by angle plates and knee braces of appropriate design forming a bridge for the tower supports.

Riveting.—All seams shall be single riveted with $\frac{5}{8}$-inch rivets on 2-inch centers, top angles and vertical stiffeners with $\frac{5}{8}$-inch rivets on 6-inch centers.

Caulking.—Bottom of condenser and partitions shall be caulked on inside, sides on outside.

Flanges.—All flanges, except draw-off flanges, shall be of standard forged steel type known as tank flanges. Draw-off flanges shall be of medium heavy forged steel, turned on bottom face to seat a 50° conical plug. The following sizes shall be furnished:

6 4-inch overflow flanges, long hub, located on long 84-foot rear side, on a line 2 feet 6 inches below top of box, centered as follows:

First flange 2 feet to left of right-hand end.
Second flange 2 feet to left of first partition.
Third flange 2 feet to left of second partition.
Fourth flange 2 feet to left of third partition.
Fifth flange 2 feet to left of fourth partition.
Sixth flange 2 feet to left of fifth partition.

6 4-inch draw-off flanges, single hub, located on the bottom, on a line parallel to 84-foot side and 23 feet 6 inches from rear of condenser, centered as follows:

First flange 1 foot to left of right-hand end.
Second flange 1 foot to left of first partition.
Third flange 1 foot to left of second partition.
Fourth flange 1 foot to left of third partition.
Fifth flange 1 foot to left of fourth partition.
Sixth flange 1 foot to left of fifth partition.

Draw-off plugs.—Each condenser compartment shall be equipped with a 4-inch conical draw-off plug operating in a special steel outlet flange. The plug shall be attached to a rod passing through a guiding strap on the inside vertical wall of the condenser, and through the angle bracket attached to top reinforcing angle, the rod projecting 3 feet above top of box and provided with T handle so it may be conveniently raised or lowered from walkway as desired. The plug shall be turned at a slightly different angle than the outlet flange to avoid binding, or approximately at 50°, and shall not exceed 6 inches in height, nor weigh over 20 pounds, exclusive of rod.

Walkway.—The condenser shall be provided with a suitable walkway, supported on top, centered midway between 84-foot sides, and extending full length. Same shall be 4 feet 4 inches in breadth, and constructed of two 8-inch 11.25-pound channel purlins, running full length of box, flanges turned out. The purlins shall be tied together at 8-foot intervals by two $\frac{3}{4}$-inch bolts centered 5 inches apart on a line at right angles to long axis of channel. Purlins shall be spaced 4 feet apart, distance to be maintained by 4-foot pipe spacers, through which tie bolts shall pass. On top of the purlin frame shall rest C. I. open checkerwork gratings 4 feet 4 inches wide by 6 feet long, provided with projecting lugs on under side, allowing easy insertion between purlins and affording readily removable treads. A suitable angle or pipe railing shall be furnished around all sides of walkway save where approaches connect.

Testing.—The condenser shall be erected on foundations approximately 20 feet above grade, and upon completion shall be tested full of water by compartments and as a whole.

One Wash Still Condenser Box

Dimensions.—The condenser shall be rectangular in shape, open-top type, 21 feet long by 14 feet wide by 5 feet deep, and shall be divided into two equal compartments 21 feet long by 7 feet wide by 5 feet deep by central partition parallel to 21-foot side.

General construction.—The condenser shall be fabricated throughout of 10.20-pound plate best grade tank or pressing steel, and shall be made up of three double courses bent on small radii (3-inch) to form sides of condenser. The 14-foot ends shall each be made from one piece of plate, and flanged-in to unite with sides and bottom of condenser.

Angle bracing.—The condenser shall be stiffened on the inside walls by a series of vertical angles $\frac{3}{8}$-inch by 3 inches by 3 inches extending from top to bottom of the condenser and located every 7 feet on the 21-foot sides. The sides of the condenser shall be further reinforced by $\frac{3}{8}$-inch by 3-inch by 3-inch angles, running completely around the top of the box. Joints shall be neatly butted and fastened with butt straps.

Cross ties.—The opposite vertical stiffening units shall be tied together with $\frac{3}{8}$-inch by 2-inch flats at the top of the condenser with $\frac{3}{8}$-inch bolts.

Riveting.—All seams shall be single riveted with $\frac{7}{16}$-inch rivets, on $1\frac{1}{2}$-inch centers, top angles and vertical stiffeners with $\frac{7}{16}$-inch rivets, on 6-inch centers.

Caulking.—The bottom of the condenser shall be caulked on the inside; sides on the outside.

Flanges.—All flanges, except draw-off flanges, shall be of standard forged steel type, known as tank flanges; draw-off flanges shall be of medium heavy forged steel, turned on bottom face to seat 50° conical plugs. The following sizes shall be furnished:

2 3-inch overflow flanges, long hub, located 14 feet from rear end, on a line 2 feet 6 inches below top of box, centered 2 feet to left of right-hand side and central partition, respectively.

2 4-inch draw-off flanges, single hub, located on the bottom, on a line parallel to 14-foot side, and 2 feet from rear end, centered 1 foot left of right-hand side and central partition, respectively.

Draw-off plugs.—Each compartment shall be equipped with a 4-inch conical draw-off plug, operating in special steel outlet flange; plug to be attached to rod passing through angle bracket attached to top reinforcing angle; rod projecting 2 feet from top of box and provided with T handle so it may be conveniently raised or lowered as desired. The plug shall be turned at a slightly different angle than the outlet flange to avoid binding, or approximately at 50°, and shall not exceed 6 inches in height nor weigh over 20 pounds exclusive of rod.

Testing.—Condenser shall be erected on foundations approximately 16 feet above grade, and upon completion shall be tested full of water by compartments and as a whole.

Ten Pumping-out Pans

Dimensions.—Each pan shall be rectangular in shape, 42 feet long by 7 feet wide by 5 feet deep, open top.

General construction.—Each pan shall be fabricated throughout of 10.20-pound best grade tank or pressing steel, and shall be made up of seven single courses bent on small radii (3 inch) to form sides of pan. The 7-foot ends shall be made from one piece of plate, and flanged-in to unite with sides and bottom of pan.

Angle bracing.—Each pan shall be stiffened on the inside walls by a series of vertical angle units $\frac{5}{16}$ inch by $2\frac{1}{2}$ inches by $2\frac{1}{2}$ inches, extending from top to bottom of pan,

located every 7 feet on the 42-foot sides. Sides shall be further reinforced by $\frac{5}{16}$-inch by $2\frac{1}{2}$-inch by $2\frac{1}{2}$-inch angles, running completely around top of box. Joints shall be neatly butted and fastened with butt straps.

Cross ties.—Opposite vertical stiffening units shall be tied together at top of pan by $\frac{3}{8}$-inch by 2-inch flats, with $\frac{5}{8}$-inch bolts.

Riveting.—All seams shall be single riveted with $\frac{7}{16}$-inch rivets on $1\frac{1}{2}$-inch centers, top angles and vertical stiffeners with $\frac{7}{16}$-inch rivets, on 6-inch centers.

Caulking.—Bottom of pan shall be caulked on inside; sides on outside.

Flanges.—All flanges, except draw-off flanges, shall be of standard forged steel type, known as tank flanges. Draw-off flanges shall be of medium heavy forged steel, turned on bottom face to seat a 50° conical plug. The following sizes shall be furnished for each pan:

1 3-inch overflow flange, long hub, located 7 feet from rear end, on a line 2 feet 6 inches below top of box, centered 2 feet to left of right-hand side.

1 4-inch draw-off flange, single hub, located on the bottom, on a line parallel to 7-foot side and 2 feet from rear end, centered 1 foot to left of right-hand side.

Draw-off plugs.—Each pan shall be equipped with a 4-inch conical draw-off plug, operating in a special steel outlet flange. The plug shall be attached to rod passing through angle bracket attached to top reinforcing angle; rod projecting 2 feet from top of box and provided with T handle so it may be conveniently raised or lowered as desired. The plug shall be turned at a slightly different angle from outlet flange to avoid binding, or approximately at 50°, exclusive of rod.

Testing.—Each pan shall be erected approximately at grade, and upon completion shall be tested full of water.

Five Flow Tanks

Dimensions.—Each tank shall be rectangular in shape, open top type, 40 feet long by 10 feet wide by 5 feet deep, and shall be divided in four equal compartments 10 feet long by 10 feet wide by 5 feet deep by partitions parallel to 10-foot end.

General construction.—Each tank shall be fabricated throughout of 9.68 pounds plate best grade tank or pressing steel, and shall be made up of seven double courses bent on small radii (3 inch) to form sides of tank. The 10-foot ends and partitions shall each be made from one or two pieces of plate, and flanged-in to unite with the sides and bottom of the tank.

Angle bracing.—Each tank shall be stiffened on the inside walls by four $\frac{5}{16}$-inch by $2\frac{1}{2}$-inch by $2\frac{1}{2}$-inch angles per side, centered between partitions, and extending from top to bottom of tank. Sides and partitions shall be further reinforced by $\frac{5}{16}$-inch by $2\frac{1}{2}$-inch by $2\frac{1}{2}$-inch angles turned in, running completely around top of box and across partitions. Joints shall be neatly butted and fastened with butt straps.

Cross ties.—Opposite vertical stiffening angles shall be tied together at top of tank by $\frac{3}{8}$ inch by 2-inch flats, with $\frac{5}{8}$-inch bolts. Two additional flats shall be bolted diagonally from the center of the top angle at each end to the side angles, as additional reinforcing units.

Riveting.—All seams shall be single riveted with $\frac{3}{8}$-inch rivets on $1\frac{1}{2}$-inch centers, top angles and vertical stiffeners with $\frac{3}{8}$-inch rivets, on $4\frac{1}{2}$-inch centers.

Caulking.—Bottom of tank shall be caulked on inside; sides on outside.

Flanges.—The following sizes shall be furnished for each tank:

4 3-inch suction flanges, long hub, located on the 40-foot side on a line 12 inches above bottom of tank, centered 12 inches to left of right-hand end and each partition.

4 2-inch water draw-off flanges, long hub, located on the 40-foot side, on a line 9 inches above bottom of tank, centered 12 inches to right of left-hand end and each partition.

Testing.—Each tank shall be erected approximately at grade. They shall be tested by compartments and as a whole.

One Flow Tank

Dimensions.—Tank shall be rectangular in shape, open-top type, 69 feet long by 8 feet wide by 6 feet deep and shall be divided in three equal compartments 23 feet long by 8 feet wide by 6 feet deep by partitions parallel to 8-foot end.

General construction.—Tank shall be fabricated throughout of 8.25-pound best grade tank or pressing steel, and shall be made up of fourteen double courses bent on small radii (3 inch) to form sides of tank. The 8-foot ends and partitions shall each be made from one or two pieces of plate flanged-in to unite with sides and bottom of tank.

Angle bracing.—Tank shall be stiffened on inside walls by six $\frac{5}{16}$-inch by 2½-inch by 2½-inch angles per side, equally spaced between partitions, and extending from top to bottom of tank. Sides and partitions shall be further reinforced by $\frac{5}{16}$-inch by 2½-inch by 2½-inch angles turned in, running completely around top of box and across partition. Joints shall be neatly butted and fastened with butt straps.

Cross ties.—Opposite vertical stiffening angles shall be tied together at top of tank by ⅜-inch by 2-inch flats, with ⅝-inch bolts. Two additional flats shall be bolted diagonally from center of top angle at each end to side angles, as additional reinforcing units.

Riveting.—All seams shall be single riveted with ⅜-inch rivets on 1½-inch centers; top angles and vertical stiffeners with ⅝-inch rivets on 4½-inch centers.

Caulking.—Bottom of tank shall be caulked on inside, sides on outside.

Flanges.—The following sizes shall be furnished for each tank:

3 2-inch water draw-off flanges, long hub, located on 69-foot side, on a line 9 inches above bottom of tank, centered 12 inches to left of right-hand end and each partition.

Testing.—Each tank shall be erected approximately at grade, and upon completion shall be tested full of water by compartments and as a whole.

Two Flow Tanks

Dimensions.—Each tank shall be rectangular in shape, open top type, 100 feet long by 8 feet wide by 6 feet deep and shall be divided into thirteen compartments by partitions parallel to the 8-foot end, compartments being 8 feet long by 6 feet deep. Partitions shall be located as follows:

First	partition, 10 feet from 8-foot end.	
Second	partition, 5 feet from first	partition.
Third	partition, 10 feet from second	partition.
Fourth	partition, 5 feet from third	partition.
Fifth	partition, 10 feet from fourth	partition.
Sixth	partition, 5 feet from fifth	partition.
Seventh	partition, 10 feet from sixth	partition.
Eighth	partition, 5 feet from seventh	partition.
Ninth	partition, 10 feet from eighth	partition.
Tenth	partition, 5 feet from ninth	partition.
Eleventh	partition, 10 feet from tenth	partition.
Twelfth	partition, 5 feet from eleventh	partition.

There will thus be formed seven compartments (10 feet by 8 feet by 6 feet), and six compartments (8 feet by 5 feet by 6 feet).

General construction.—Each tank shall be fabricated throughout of 8.25-pound best grade tank or pressing steel, and shall be made up of twenty-one double courses bent on small radii (3 inch) to form sides of tank. The 8-foot ends and partitions shall each be made from one or two pieces of plate, flanged-in to unite with sides and bottom of tank.

Angle bracing.—Each tank shall be stiffened on inside walls by seven 5/16-inch by 2½-inch by 2½-inch angles per side, centered between 10-foot partitions and extending from top to bottom of tank. Sides and partitions shall be further reinforced by 5/16-inch by 2½-inch by 2½-inch angles turned-out, running completely around top of box and across partitions. Joints shall be neatly butted and fastened with butt straps.

Cross ties.—Opposite vertical stiffening angles shall be tied together at top of tank by ⅜-inch by 2-inch flats, with ⅝-inch bolts. Two additional flats shall be bolted diagonally from the center of the top angle at each end and to the side angles, as additional reinforcing units.

Riveting.—All seams shall be single riveted with ⅝-inch rivets, on 1½-inch centers, top angles and vertical stiffeners with ⅝-inch rivets, on 4½-inch centers.

Caulking.—Bottom of tank shall be caulked on inside; sides on outside.

Testing.—Each tank shall be erected on foundations approximately at grade, and upon completion shall be tested full of water by compartments and as a whole.

Three Refined Oil Agitators—2000 Barrels

Dimensions.—Each agitator shall be of vertical type, closed top, 25 feet diameter by 36 feet 5 inches high.

General construction.—Each agitator shall be made of a six-course shell, of best quality tank steel; to the first and second rings of which, and erected vertically on equidistant radial lines, six gusset plates, also of tank steel, shall be framed on inside. Supported by the latter, and joined to the shell at the top of the second ring, shall be located a 30° cone, to be fabricated from twenty segmental plates and one circular dished bottom plate of best grade flange steel. The cone shall be flanged-in to fit inside of shell with a flange of 6-inch width, cone apex to be 6 feet above bottom of agitator. In first ring, centered between supporting gussets shall be located two door-ways 3 feet by 7 feet, directly opposite each other. The following weights of plate shall be used in the above construction:

First ring........17.85 pounds	Fifth ring.....12.75 pounds
Second ring......17.85 pounds	Sixth ring.....12.75 pounds
Third ring.......15.30 pounds	Gusset plates..17.85 pounds
Fourth ring......15.30 pounds	Cone plates....17.85 pounds

Angle bracing.—Around the bottom of each agitator shall be riveted inside and outside ⅜-inch by 3-inch by 3-inch angles, while around the top of the shell shall be one angle 5/16-inch by 2½-inch by 2½-inch turned on outside. Around the gusset plates, on each side shall also be riveted ⅜-inch by 3-inch by 3-inch angles. Door entrances shall also be reinforced with the same weight angle on the outside of the shell only.

Riveting.—All holes in and above the cone shall be countersunk inside; the following schedule of rivets shall be adopted:

Location	Riveting circular seams	Riveting vertical seams
Bottom angles to 1st ring	¾-inch R., 3-inch P., S.R.L.	
1st ring to 2d	¾-inch R., 2¼ inch P., S.R.L.	¾-inch R., 3-inch P., D.R.L.
2d to cone flange	¾-inch R., 2¼-inch P., S.R.L. (C.S.)	¾-inch R., 3-inch P., D.R.L.
Cone flange to 3d	¾-inch R., 2¼-inch P., S.R.L. (C.S.)	
3d to 4th	¾-inch R., 2¼-inch P., S.R.L. (C.S.)	¾-inch R., 2½-inch P., D.R.L. (C.S.)
4th to 5th	¾-inch R., 2¼-inch P., S.R.L. (C.S.)	¾-inch R., 2½-inch P., D.R.L. (C.S.)
5th to 6th	⅝-inch R., 2¼-inch P., S.R.L. (C.S.)	⅝-inch R., 2¼-inch P., D.R.L. (C.S.)
6th		⅝-inch R., 2¼-inch P., D.R.L. (C.S.)
6th to top angle	⅝-inch R., 3-inch P., S.R.L.	
Top angle to roof	$\frac{7}{16}$-inch R., 3-inch P., S.R.L.	

Location	Miscellaneous
Angles to gussets	¾-inch R., 3-inch P., S.R.L.
Angles to cone	¾-inch R., 3-inch P., S.R.L.
Segmental cone plates	¾-inch R., 2¼-inch P., S.R.L.
Roof plates	⅝-inch R., 2-inch P., S.R.L.

Caulking.—All seams in cone shall be caulked on inside, all shell seams above cone on outside. Caulking is not required on the shell seams below the cone.

Fittings.—Each agitator shall be equipped with the following attachments:

1 6-inch bronze outlet nozzle with upper flange cast to fit agitator cone, and lower provided with 6-inch tap companion flange, fitted with necessary standard bolts.

12 18-inch diameter explosion hatches fitted with self-closing doors, to be applied on roof, equal distances apart, centered 2 feet from edge.

1 Standard ventilator, located center of roof.

Roof.—Roof shall be of self-supporting globe type, constructed of twenty-four segmental plates of 7.65-pound tank steel, and attached to agitator by bolting to top angle ring.

Stairway and gallery.—Each agitator shall be provided with a standard gallery, with pipe railing and steel flooring, supported by means of structural steel brackets riveted to shell. The floor of the gallery shall be 3 feet below top of agitator. The galleries of the three agitators shall be connected with suitable bridges if the distance between centers permits (not exceeding 75 feet); connecting bridges to be furnished in lieu of one stairway. The three agitators shall be supplied preferably with two stairways, one for each outside agitator with connecting bridges between. Stairways shall be of standard steel construction, furnished with suitable pipe railings.

Testing.—Agitators shall be erected substantially at grade.

Six Lubricating Oil Agitators—600 Barrels

Dimensions.—Each agitator shall be of vertical type, closed top, 18 feet diameter by 31 feet high.

General construction.—Each agitator shall be made up of a five-course shell of best quality tank steel. To the first, second and third rings of this, erected vertically on equidistant radial lines, shall be framed on inside six gusset plates, also of tank steel. Supported by the latter, and joined to shell at top of third ring, shall be located a 50-degree cone, to be fabricated from eight segmental plates and one conical bottom plate of best grade flange steel. The cone shall be flanged-in to fit inside of shell with a flange of 6-inch width, cone apex to be 7 feet 6 inches above bottom of agitator. In first ring, centered between supporting gussets, shall be located two

door-ways 3 feet by 6 feet, directly opposite each other, same to be provided with light reinforced plate doors. The following weights of plate shall be used in above construction:

First ring.........15.30 pounds	Fifth ring........12.75 pounds
Second ring.......15.30 pounds	Gusset plates.....15.30 pounds
Third ring.......15.30 pounds	Cone plates......20.40 pounds
Fourth ring.......15.30 pounds	

Angle bracing.—Around the bottom of each agitator shall be riveted inside and outside 3/8-inch by 3-inch by 3-inch angles, while around top of shell shall be one angle 1/4-inch by 2 inches by 2 inches turned on outside. Around gusset plates, one side shall also be riveted 3/8-inch by 3-inch by 3-inch angles. The door entrances shall also be reinforced with same weight of angle on outside of shell only.

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Bottom angles to 1st ring.............. 1st ring to 2d........	3/4-inch R., 3 -inch P., S.R.L.	 3/4-inch R., 3-inch P., D.R.L.
2d to 3d..............	3/4-inch R., 2½-inch P., S.R.L.	3/4-inch R., 3-inch P., D.R.L.
3d to cone.............	7/8-inch R., 2½-inch P., S.R.L.	3/4-inch R., 3 -inch P., D.R.L.
Cone to 4th............	5/8-inch R., 2¼-inch P., S.R.L.	
4th to 5th.............	5/8-inch R., 2¼-inch P., S.R.L.	5/8-inch R., 2¼-inch P., S.R.L.
5th..		5/8-inch R., 2¼-inch P., S.R.L.
5th to top angle........	5/8-inch R., 3 -inch P., S.R.L.	
Top angle to roof.......	7/16-inch R., 3 -inch P., S.R.L.	

Location	Miscellaneous
Angles to gussets....................	3/4-inch R., 3 -inch P., S.R.L.
Angles to cone......................	3/4-inch R., 3 -inch P., S.R.L.
Segemental cone plates...............	5/8-inch R., 2¼-inch P., S.R.L.
Roof plates.........................	5/8-inch R., 2¼-inch P., S.R.L.

Caulking.—All seams in cone shall be caulked on inside; all shell seams above cone on outside; caulking is not required on shell seams below cone.

Fittings.—Each agitator shall be equipped with the following attachments:

1 6-inch bronze outlet nozzle with upper flange cast to fit agitator cone, and lower provided with 6-inch tap companion flange, fitted with necessary standard bolts.

4 18-inch diameter explosion hatches fitted with self-closing doors to be applied on roof equal distances apart, centered 2 feet from edge.

1 Standard ventilator, located center of roof.

Roof.—Roof shall be of self-supporting globe type, constructed of twelve segmental plates of 7.65-pound tank steel, and attached to agitator by bolting to top angle ring.

Stairway and gallery.—Each agitator shall be provided with a standard gallery, with pipe railing and steel flooring, supported by means of structural steel brackets riveted to shell. Floor of gallery shall be 3 feet below top of shell. Galleries of the six agitators shall be connected with suitable bridges if distance between centers permits (not exceeding 75 feet). Connecting bridges shall be furnished in lieu of four stairways. The six agitators shall be supplied preferably with two stairways, one for each of the two outside agitators with connecting bridges between. Stairways shall be of standard steel construction, furnished with suitable pipe railings.

Testing.—Agitators shall be erected substantially at grade.

Twenty Filters

Dimensions.—Filters shall be of vertical type, 8 feet in diameter by 20 feet high, in the shell.

Shell.—Shell shall be made of four roundabout courses of the best quality of tank steel of the following weights:

First ring	15.30 pounds	Third ring	12.75 pounds
Second ring	15.30 pounds	Fourth ring	12.75 pounds

Heads.—Heads shall each be made from one piece of 17.85-pound plate best quality flange steel, standard O. D. and flanged-in.

Lugs.—Each filter shall be provided with four C. I. lugs 18 inches wide by 24 inches long, lugs to be centered 90° from each other. Bases shall lie in a line 5 feet 6 inches above bottom of shell.

Riveting.—All riveting shall be in accordance with the following schedule:

Rings	Riveting circular seams	Riveting vertical seams
1 to bottom head	¾-inch R., 3 -inch P., D.R.L.	
1 to 2	¾-inch R., 3 -inch P., D.R.L.	¾-inch R., 3-inch P., D.R.L.
2 to 3	¾-inch R., 2¼-inch P., S.R.L.	¾-inch R., 3-inch P., D.R.L.
3 to 4	¾-inch R., 2¼-inch P., S.R.L.	¾-inch R., 3-inch P., D.R.L.
4		¾-inch R., 3-inch P., D.R.L.
4 to top head	¾-inch R., 2¼-inch P., S.R.L.	
	Lugs to shell ⅞-inch R., 2½-inches P.	

Caulking.—All seams shall be caulked.

Flanges.—The following sizes shall be furnished for each filter:

1 3-inch outlet flange, centered on the bottom of filter.
4 2½-inch service flanges, located on the top of filter, on a line directly over line passing through centers of any two opposite lugs, centered equidistant from shell sides 1 foot apart.

Mannecks.—Each filter shall be provided with two plate mannecks; one 18-inch diameter centered in the top of filter; one 18-inch diameter ends by 36 inches long, centered with long axis parallel to long axis of filter as close to bottom as good practice will allow, directly under either lug at 90° to top row of flanges. Top plate will be secured by twenty-two ¾-inch standard bolts, side plate requiring fifty of same size.

Gratings.—Each filter shall be provided with a set of gratings or false bottom, of 15.30-pound plate, to be supported 6 inches above bottom, by a ⅜-inch by 3-inch by 3-inch angle ring riveted around inside of shell, and by four angles of same weight riveted across shell. Grating plates shall be cut in strips sufficiently narrow to pass readily through manneck, shall rest without fastening on supports, and shall be perforated with ½-inch holes on 1½-inch centers.

Testing.—Filters shall be fabricated in shop, and tested under 75-pounds hydrostatic pressure.

Two Storage Tanks—55,000 Barrels

Dimensions.—Tanks shall be of vertical type, tight steel roof, 114 feet 6 inches diameter by 30 feet 2¾ inches high in the shell.

General construction.—Each tank shall be constructed throughout of the best quality of tank steel. Bottom plates shall be joined to shell by means of an angle ring turned inside, to which bottom and shell shall each be riveted. Upper course of shell

shall be reinforced with an angle ring turned-out to which roof sheets shall be attached. Plates and angles shall be of the following weights and sizes:

Bottom rectangles.......... 8.25 pounds	Third ring..............12.75 pounds
Bottom sketches............ 9.68 pounds	Fourth ring.............10.20 pounds
First ring..................20.40 pounds	Fifth ring............... 8.25 pounds
Second ring................17.85 pounds	Roof plates.............. 5.47 pounds
Bottom angles, ½-inch by 4 inches by 4 inches	Top angle, ⅜-inch by 3 inches by 3 inches

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle.	¾-inch R., 2¼-inch P., S.R.L.	
Bottom angle to 1st ring.	¾-inch R., 2¼-inch P., S.R.L.	
1st to 2d..............	¾-inch R., 2¼-inch P., S.R.L.	¾-inch R., 2¼-inch P., T.R.L.
2d to 3d...............	¾-inch R., 2¼-inch P., S.R.L.	¾-inch R., 2¼-inch P., T.R.L.
3d to 4th..............	⅝-inch R., 2 -inch P., S.R.L.	⅝ inch R., 2¼-inch P., D.R.L.
4th to 5th.............	7/16-inch R., 1½-inch P., S.R.L.	½-inch R., 1¾-inch P., D.R.L.
5th..		7/16-inch R., 1¾-inch P., D.R.L.
5th to top angle........	7/16-inch R., 2¼-inch P., S.R.L.	
Top angle to roof.......	7/16-inch R., 1½-inch P., S.R.L.	

Location	Miscellaneous
Bottom rectangles..................	7/16-inch R., 1½-inch P., S.R.L.
Bottom sketches....................	7/16-inch R., 1½-inch P., S.R.L.
Roof plates........................	⅝-inch R., 2 -inch P., S.R.L.

Caulking.—All the bottom seams and the bottom angle shall be caulked inside, shell seam outside, roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 8-inch suction flange, long hub, located in the shell, centered on a line 18 feet above bottom of tank, and 2 feet to right of manhole.

1 6-inch discharge flange, single hub, located in the shell, centered on a line 12 inches below top, and 2 feet to right of 8-inch suction flange.

1 4-inch water draw-off flange, long hub, located in the shell, centered on a line 9 inches above bottom of tank and 4 feet to right of 8-inch suction flange.

1 2½-inch steam fire flange, single hub, located in the shell, centered on a line 9 inches below top, and 4 feet to right of 6-inch discharge flange.

Swing Pipe.—Each tank shall be furnished with one 8-inch swing pipe. See previous tank specifications.

Manholes.—Each tank shall be provided with two manholes; one 20-inch C. I. manhole in center of first ring, to be provided with caulking strip at point of attachment; one 20-inch steel plate neck, located in the roof of tank as close to shell as good practice will allow, centered directly over side neck. Angle ring of lower neck shall be faced true, also cast-iron cover plate for a corresponding distance. Top neck shall be provided with a light hinged cover closing gas-tight.

Stairway.—Standard steel stairs with cab shall be furnished with each tank.

Roof supports.—Nine-inch channel rafters, resting on circular purlin rings, in turn supported by columns of adequate strength shall form roof supports.

Testing.—Each tank shall be tested when bottom ring is in position, and again upon completion in accordance with the general procedure for tests.

Two Storage Tanks—37,500 Barrels

Dimensions.—Tanks shall be of vertical type, tight steel roof, 95 feet 6 inches diameter by 29 feet high in the shell.

General construction.—See previous tank specifications. Plates and angles shall be of the following weights and sizes:

Bottom rectangles	8.25 pounds	Third ring	12.75 pounds
Bottom sketches	8..97 pounds	Fourth ring	10.20 pounds
First ring	17.85 pounds	Fifth ring	8.25 pounds
Second ring	15.50 pounds	Roof plates	5.47 pounds
Bottom angle	½ inch × 4 inches × 4 inches	Top angle	⅜ inch × 2½ inches × 2½ inches

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle	⅝-inch R., 2-inch P., S.R.L.	
Bottom angle to 1st ring	¾-inch R., 2¼-inch P., S.R.L.	
1st to 2d	¾-inch R., 2¼-inch P., S.R.L.	¾-inch R., 2¼-inch P., T.R.L.
2d to 3d	¾-inch R., 2¼-inch P., S.R.L.	¾-inch R., 2¼-inch P., D.R.L.
3d to 4th	⅝-inch R., 2¼-inch P., S.R.L.	⅝-inch R., 2¼-inch P., D.R.L.
4th to 5th	7/16-inch R., 1½-inch P., S.R.L.	⅝-inch R., 2¼-inch P., D.R.L.
5th		7/16-inch R., 1¾-inch P., D.R.L.
5th to top angle	7/16-inch R., 2¼-inch P., S.R.L.	
Top angle to roof	7/16-inch R., 1½-inch P., S.R.L.	

Location	Miscellaneous
Bottom rectangles	7/16-inch R., 1½-inch P., S.R.L.
Bottom sketches	7/16-inch R., 1½-inch P., S.R.L.
Roof plates	⅝-inch R., 2-inch P., S.R.L.

Caulking.—All bottom seams and bottom angle shall be caulked inside, shell seam outside; roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 8-inch suction flange, long hub, located in shell, centered on a line 18 inches above bottom of tank, and 2 feet to right of manhole.

1 6-inch discharge flange, single hub, located in shell, centered on a line 12 inches below top, and 2 feet to right of 8-inch suction flange.

1 4-inch water draw-off flange, long hub, located in shell, centered on a line 9 inches above bottom of tank and 4 feet to right of 8-inch suction flange.

1 2½-inch steam fire flange, single, hub, located in shell, centered on a line 9 inches below top, and 4 feet to right of 6-inch discharge flange.

Swing pipe.—Each tank shall be furnished with one 8-inch swing pipe. See previous tank specifications.

Manholes.—See previous tank specifications.

Stairway.—Standard steel stairs with cab shall be furnished with each tank.

Roof supports.—Nine-inch channel rafters, resting on circular purlin rings in turn supported by columns of adequate strength shall form roof supports.

Testing.—Each tank shall be tested when bottom ring is in position, and again upon completion in accordance with the general procedure for tests.

Five Storage Tanks—20,000 Barrels

Dimensions.—Tanks shall be of vertical type, tight steel roof, 70 feet diameter by 29 feet 3 inches in the shell.

General construction.—See previous tank specifications. Plates and angles shall be of following weights and sizes:

Bottom rectangles	8.25 pounds	Third ring	10.20 pounds
Bottom shetches	8.25 pounds	Fourth ring	8.92 pounds
First ring	12.75 pounds	Fifth ring	8.25 pounds
Second ring	11.47 pounds	Roof plates	5.47 pounds
Bottom angle	$\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $3\frac{1}{2}$ in.	Top angle	$\frac{5}{16}$ in. × $2\frac{1}{2}$ in. × $2\frac{1}{2}$ in.

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle	$\frac{5}{8}$-inch R., $2\frac{1}{4}$-inch P., S.R.L.	
Bottom angle to 1st ring	$\frac{5}{8}$-inch R., $2\frac{1}{4}$-inch P., S.R.L.	
1st to 2d	$\frac{5}{8}$-inch R., $2\frac{1}{4}$-inch P., S.R.L.	$\frac{3}{4}$-inch R., $2\frac{3}{4}$-inch P., D.R.L.
2d to 3d	$\frac{5}{8}$-inch R., $2\frac{1}{4}$-inch P., S.R.L.	$\frac{5}{8}$-inch R., $2\frac{1}{2}$-inch P., D.R.L.
3d to 4th	$\frac{5}{8}$-inch R., $2\frac{1}{4}$-inch P., S.R.L.	$\frac{5}{8}$-inch R., $2\frac{1}{2}$-inch P., D.R.L.
4th to 5th	$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.	$\frac{7}{16}$-inch R., $1\frac{3}{4}$-inch P., D.R.L.
5th		$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.
5th to top angle	$\frac{7}{16}$-inch R., $2\frac{1}{4}$-inch P., S.R.L.	
Top angle to roof	$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.	

Location	Miscellaneous
Bottom rectangles	$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.
Bottom sketches	$\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.
Roof plates	$\frac{3}{8}$-inch R., 2-inch P., S.R.L.

Caulking.—All bottom seams and the bottom angle shall be caulked inside, shell seam outside; roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 6-inch suction flange, long hub, located shell, centered on a line 18 inches above bottom of tank, and 2 feet to right of manhole.

1 6-inch discharge flange, single hub, located shell, centered on a line 12 inches below top, and 2 feet to right of 6-inch suction flange.

1 4-foot water draw-off flange, long hub, located shell, centered on a line 9 inches above bottom of tank and 4 feet to right of 8-inch suction flange.

1 2-inch steam fire flange, single hub, located shell, centered on a line 9 inches below top, and 4 feet to right of 6-inch discharge flange.

Swing pipe.—Each tank shall be furnished with one 6-inch swing pipe. See previous tank specifications.

Manholes.—See previous tank specifications.

Stairway.—Standard steel stairs with cab shall be furnished with each tank.

Roof supports.—Special steel trusses framed to shell and to plate in center, constituting roof rafters, shall form roof supports.

Testing.—Each tank shall be tested when bottom ring is in position, and again upon completion in accordance with the general procedure for tests.

Sixteen Storage Tanks—10,000 Barrels

Dimensions.—Tanks shall be of vertical type, tight steel roof, 50 feet in diameter by 29 feet 3 inches high in the shell.

General construction.—See previous tank specifications. Plates and angles shall be of the following weights and sizes:

Bottom rectangles	8.25 pounds	Third ring	9.68 pounds
Bottom sketches	8.25 pounds	Fourth ring	8.25 pounds
First ring	12.75 pounds	Fifth ring	8.25 pounds
Second ring	10.20 pounds	Roof plates	5.47 pounds
Bottom angle, 5/16-inch by 3-inch by 3-inch		Top angle, 1/4-inch by 2 1/2-inch by 2 1/2-inch	

Riveting.—Riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle	5/8-inch R., 2 1/4-inch P., S.R.L.	
Bottom angle to 1st ring	5/8-inch R., 2 1/4-inch P., S.R.L.	
1st to 2d	5/8-inch R., 2 1/4-inch P., S.R.L.	5/8-inch R., 2 1/2-inch P., D.R.L.
2d to 3d	7/16-inch R., 1 1/2-inch P., S.R.L.	5/8-inch R., 2 1/2-inch P., D.R.L.
3d to 4th	7/16-inch R., 1 1/2-inch P., S.R.L.	7/16-inch R., 1 3/4-inch P., D.R.L.
4th to 5th	7/16-inch R., 1 1/2-inch P., S.R.L.	7/16-inch R., 1 3/4-inch P., D.R.L.
5th		7/16-inch R., 1 1/2-inch P., S.R.L.
5th to top angle	7/16-inch R., 2 1/4-inch P., S.R.L.	
Top angle to roof	7/16-inch R., 1 1/2-inch P., S.R.L.	

Location	Miscellaneous
Bottom rectangles	7/16-inch R., 1 1/2-inch P., S.R.L.
Bottom sketches	7/16-inch R., 1 1/2-inch P., S.R.L.
Roof plates	5/8-inch R., 2 -inch P., S.R.L.

Caulking.—All bottom seams and the bottom angle shall be caulked inside, shell seam outside, caulking of roof not required.

Flanges.—Each tank shall be provided with the following flanges:

- 1 6-inch suction flange, long hub, located in shell, centered on a line 18 inches above bottom of tank, and 2 feet to right of manhole.
- 1 6-inch discharge flange, single hub, located in shell, centered on a line 12 inches below top, and 2 feet to right of 6-inch suction flange.
- 1 3-inch water draw-off flange, long hub, located in shell, centered on a line 8 inches above bottom of tank and 4 feet to right of 6-inch suction flange.
- 2 2-inch steam fire flange, single hub, located in shell, centered on a line 9 inches below top, and 4 feet to right of 6-inch discharge flange.

Swing pipe.—Each tank shall be furnished with one 6-inch swing pipe. See previous tank specifications.

Manholes.—See previous tank specifications.

Stairway.—Standard steel stairs shall be furnished with each tank.

Roof supports.—Special steel trusses framed to shell and to plate in center, constituting roof rafters, shall form roof supports.

Testing.—Each tank shall be tested when bottom ring is in position, and again upon completion in accordance with the general procedure for tests.

Four Working Tanks—5000 Barrels

Dimensions.—Each tank shall be of vertical type, tight steel roof, 35 feet diameter by 30 feet high in the shell.

General construction.—See previous tank specifications. Plates and angles shall be of the following weights and sizes:

Bottom rectangles	8.25 pounds	Fourth ring	8.25 pounds
Bottom sketches	8.25 pounds	Fifth ring	8.25 pounds
First ring	10.20 pounds	Sixth ring	7.65 pounds
Second ring	9.68 pounds		
Third ring	8.92 pounds	Roof plates	5.10 pounds
Bottom angle, 5/16-inch by 2½-in. by 2½-in.		Top angle, ¼-inch by 2-in. by 2-in.	

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle	⅝-inch R., 2¼-inch P., S.R.L.	
Bottom angle to 1st ring	⅝-inch R., 2¼-inch P., S.R.L.	
1st to 2d	⅝-inch R., 2¼-inch P., S.R.L.	⅝-inch R., 2½-inch P., D.R.L.
2d to 3d	7/16-inch R., 1½-inch P., S.R.L.	⅝-inch R., 2½-inch P., D.R.L.
3d to 4th	7/16-inch R., 1½-inch P., S.R.L.	7/16-inch R., 1¾-inch P., D.R.L.
4th to 5th	7/16-inch R., 1½-inch P., S.R.L.	7/16-inch R., 1¾-inch P., D.R.L.
5th to 6th	7/16-inch R., 1½-inch P., S.R.L.	7/16-inch R., 1¾-inch P., D.R.L.
6th		7/16-inch R., 1½-inch P., S.R.L.
6th to top angle	7/16-inch R., 1½-inch P., S.R.L.	
Top angle to roof	7/16-inch R., 1½-inch P., S.R.L.	

Location	Miscellaneous
Bottom rectangles	7/16-inch R., 1½-inch P., S.R.L.
Bottom sketches	7/16-inch R., 1½-inch P., S.R.L.
Roof plates	⅝-inch R., 1½-inch P., S.R.L.

Caulking.—All bottom seams and bottom angle shall be caulked inside, shell seam outside; caulking of roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 4-inch suction flange, long hub, located in shell, centered on a line 18 inches above bottom of tank, and 2 feet to right of manhole.

1 4-inch discharge flange, single hub, located in shell, centered on a line 9 inches below top, and 2 feet to right of 4-inch suction flange.

1 3-inch water draw-off flange, long hub, located in shell, centered on a line 8 inches above bottom of tank and 4 feet to right of 4-inch suction flange.

1 2-inch steam fire flange, single hub, located in shell, centered on a line 9 inches below top, and 4 feet to right of 4-inch discharge flange.

Swing pipe.—Each tank shall be furnished with one 4-inch swing pipe. See previous tank specifications.

Manholes.—See previous tank specifications.

Stairway.—Standard steel stairs will be furnished with each tank.

Roof supports.—Roof shall be of self-supporting globe type, fabricated from twenty-eight segmental plates of 11 gage or 5.1-pound sheets.

Testing.—Each tank shall be tested when bottom ring is in position, and again upon completion in accordance with the general procedure for tests.

Ten Working Tanks—2500 Barrels

Dimensions.—Each tank shall be of vertical type, tight steel roof, 25 feet diameter by 30 feet high in the shell.

General construction.—See previous tank specifications. Plates and angles shall be of the following weights and sizes:

Bottom rectangles............7.65 pounds	Fourth ring...........8.25 pounds
Bottom sketches..............8.25 pounds	Fifth ring.............7.65 pounds
First ring...................9.68 pounds	Sixth ring.............7.65 pounds
Second ring..................8.92 pounds	
Third ring...................8.25 pounds	Roof plates............4.46 pounds
Bottom angle, 5/16-inch by 2½-in. by 2½-in.	Top angle, ¼-inch by 2 in. by 2 in.

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle.	5/8-inch R., 2¼-inch P., S.R.L.	
Bottom angle to 1st ring.	5/8-inch R., 2¼-inch P., S.R.L.	
1st to 2d.............	5/8-inch R., 2¼-inch P., S.R.L.	5/8-inch R., 2½-inch P., D.R.L.
2d to 3d..............	7/16-inch R., 1½-inch P., S.R.L.	7/16-inch R., 1¾-inch P., D.R.L.
3d to 4th.............	7/16-inch R., 1½-inch P., S.R.L.	7/16-inch R., 1¾-inch P., D.R.L.
4th to 5th............	7/16-inch R., 1½-inch P., S.R.L.	7/16-inch R., 1¾-inch P., D.R.L.
5th to 6th............	7/16-inch R., 1½-inch P., S.R.L.	7/16-inch R., 1¾-inch P., D.R.L.
6th....................		7/16-inch R., 1½-inch P., S.R.L.
6th to top angle........	7/16-inch R., 1½-inch P., S.R.L.	
Top angle to roof......	7/16-inch R., 1½-inch P., S.R.L.	

Location	Miscellaneous
Bottom rectangles..................	7/16-inch R., 1½-inch P., S.R.L.
Bottom sketches....................	7/16-inch R., 1½-inch P., S.R.L.
Roof plates........................	3/8-inch R., 1½-inch P., S.R.L.

Caulking.—All bottom seams and bottom angle shall be caulked inside, shell seams outside; caulking of roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 4-inch suction flange, long hub, located in shell, centered on a line 18 inches above bottom of tank, and 2 feet to right of manhole.

1 3-inch discharge flange, single hub, located in shell, centered on a line 9 inches below top, and 2 feet to right of 4-inch suction flange.

1 3-inch water draw-off flange, long hub, located in shell centered on a line 8 inches above bottom of tank and 4 feet to right of 4-inch suction flange.

1 2-inch steam fire flange, single hub, located in shell, centered on a line 9 inches below top, and 4 feet to right of 3-inch discharge flange.

2 1-inch steam flanges, long hub, located in shell, one centered on a line 14 inches above bottom, 1 foot to right of water draw-off flange; one centered on a line 8 inches above bottom, 1 foot to right of first flange.

Swing pipe.—Each tank shall be furnished with one 4-inch swing pipe. See previous tank specifications.

Manholes.—Each tank shall be provided with two manholes; one 20-inch C. I. manhole in center of first ring, to be provided with 3/8-inch by 40-inch by 40-inch reinforcing plate at point of attachment; one 20-inch steel plate neck, located roof of tank as close to shell as good practice will allow, centered directly over side neck. See previous tank specifications.

Stairway.—Standard steel stairs shall be furnished with each tank.

Roof supports.—Roof shall be of self-supporting globe type fabricated from twenty-four segmental plates of 12 gage or 4.46-pound sheets.

Testing.—Each tank shall be tested when bottom ring is in position, and again upon completion in accordance with the general procedure for tests.

Six Bleachers (Refined Oil) 2500 Barrels

Dimensions.—Each bleacher shall be of vertical type, tight steel roof, 43 feet diameter by 10 feet high in the shell.

General construction.—See previous tank specifications. Plates and angles shall be of the following weights and sizes:

Bottom rectangles	7.32 pounds	Second ring	7.65 pounds
Bottom sketches	7.65 pounds	Roof plates	5.10 pounds
First ring	8.25 pounds	Top angle	¼ in. × 2 in. × 2 in.
Bottom angle	5/16 in. × 2½ in. × 2½ in.		

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle	7/16-inch R., 1½-inch P., S.R.L.	
Bottom angle to 1st ring	7/16-inch R., 1½-inch P., S.R.L.	
1st to 2d	7/16-inch R., 1½-inch P., S.R.L.	7/16-inch R., 1¾-inch P., D.R.L.
2d		7/16-inch R., 1½-inch P., S.R.L.
2d to top angle	7/16-inch R., 1½-inch P., S.R.L.	
Top angle to roof	7/16-inch R., 1½-inch P., S.R.L.	

Location	Miscellaneous
Bottom rectangles	7/16-inch R., 1½-inch P., S.R.L.
Bottom sketches	7/16-inch R., 1½-inch P., S.R.L.
Roof plates	⅜-inch R., 1½-inch P., S.R.L.

Caulking.—All bottom seams and bottom angle shall be caulked inside, shell seam outside, caulking of roof not required.

Flanges.—Each tank shall be provided with the following flanges:

- 1 6-inch suction flange, long hub, located in shell, centered on a line 18 inches above bottom of tank, and 2 feet to right of manhole.
- 1 6-inch run-down flange, single hub, located in shell, centered on a line 12 inches below top, and 2 feet to right of 6-inch suction flange.
- 1 3-inch water draw-off flange, long hub, located in shell, centered on a line 8 inches above bottom of tank and 4 feet to right of 6-inch suction flange.
- 1 2-inch steam fire flange, single hub, located in shell, centered on a line 9 inches below top, and 4 feet to right of 6-inch run-down flange.
- 2 1-inch steam flanges, long hub, located in shell, one centered on a line 14 inches above bottom, 1 foot to right of water draw-off flange; and centered on a line 8 inches above bottom, 1 foot to right of first flange.

Swing pipe.—Each bleacher shall be furnished with one 6-inch swing pipe. See previous tank specifications.

Manholes.—Each bleacher shall be provided with two manholes; one 20-inch C. I. manhole in center of first ring, to be provided with 5/16-inch by 40-inch by 40-inch reinforcing plate at point of attachment; one 20-inch steel plate neck, located roof of tank as close to shell as good practice will allow, centered 3 feet to left of side neck. See previous tank specifications.

Hatches.—Each bleacher shall be provided with six 24-inch by 36-inch hatches fitted with self-closing gas-tight doors, to be located on roof, centered with their short axes on radial lines; each hatch 14 feet from apex of cone, spaced 60° apart, angles of hatch frame to be sheared and caulked to roof.

Ladder.—Each bleacher shall be provided with a standard steel ladder on the outside, located 3 feet to left of lower manhole.

Roof supports.—Special steel trusses framed to shell and to plate in center, constituting roof rafters, shall form roof supports.

Testing.—Each bleacher shall be tested when bottom ring is in position, and again when completed.

Six Bleachers (Lubricating Oil)—1600 Barrels

Dimensions.—Each bleacher shall be of vertical type, tight steel roof, 34 feet diameter by 10 feet high in the shell.

General construction.—See previous specifications. Plates and angles shall be of following weights and sizes:

Bottom rectangles	7.32 pounds
Bottom sketches	7.65 pounds
First ring	8.25 pounds
Bottom angle	5/16 in. × 2½ in. × 2½ in.
Second ring	7.65 pounds
Roof plates	5.10 pounds
Top angle	⅜ in. × 2 in. × 2 in.

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle	7/16-inch R., 1½-inch P., S.R.L.	
Bottom angle to 1st ring	7/16-inch R., 1½-inch P., S.R.L.	
1st to 2d	7/16-inch R., 1½-inch P., S.R.L.	7/16-inch R., 1¾-inch P., D.R.L.
2d		7/16-inch R., 1½-inch P., S.R.L.
2d to top angle	7/16-inch R., 1½-inch P., S.R.L.	
Top angle to roof	7/16-inch R., 1½-inch P., S.R.L.	

Location	Miscellaneous
Bottom rectangles	7/16-inch R., 1½-inch P., S.R.L.
Bottom sketches	7/16-inch R., 1½-inch P., S.R.L.
Roof plates	⅜-inch R., 1½-inch P., S.R.L.

Caulking.—All bottom seams and the bottom angle shall be caulked inside, shell seam outside, caulking of roof not required.

Flanges.—Each bleacher shall be provided with the following flanges:

1 6-inch suction flange, long hub, located in shell, centered on a line 18 inches above bottom of tank, and 2 feet to right of manhole.

1 6-inch run-down flange, single hub, located in shell, centered on a line 24 inches below top, and 2 feet to right of 6-inch suction flange.

1 3-inch water draw-off flange, long hub, located in shell, centered on a line 8 inches above bottom of tank and 4 feet to right of 6-inch suction flange.

1 2-inch steam fire flange, single hub, located in shell, centered on a line 9 inches below top, and 4 feet to right of 6-inch run-down flange.

2 1-inch steam flanges, long hub, located in shell, one centered on a line 14 inches above bottom, 1 foot to right of water draw-off flange; one centered on a line 8 inches above bottom, 1 foot to right of first flange.

Swing pipe.—Each bleacher shall be furnished with one 6-inch swing pipe. See previous tank specifications.

Manholes.—Each bleacher shall be provided with two manholes; one 20-inch C. I. manhole in center of first ring, to be provided with $\frac{5}{16}$-inch by 40-inch by 40-inch reinforcing plate at point of attachment; one 20-inch steel plate neck, located roof of tank as close to shell as good practice will allow, centered 3 feet to left of side neck. See previous tank specifications.

Hatches.—Each bleacher shall be provided with six 12-inch by 30-inch hatches fitted with self-closing gas-tight doors, to be located on shell, centered with their axes on a line parallel to bottom of tank 12 inches below roof. The hatches shall be spaced 60° apart; angles of hatch frame to be sheared and caulked to shell.

Ladder.—Each bleacher shall be provided with a standard steel ladder on the outside, located 3 feet to left of lower manhole.

Roof supports.—Roof shall be of self-supporting globe type, fabricated from eighteen segmental plates of 11 gage or 5.10-pound sheets.

Testing.—Each bleacher shall be tested when bottom ring is in position, and again upon completion.

Thirty-two Run-down Tanks—1600 Barrels

Dimensions.—Each tank shall be of vertical type, tight steel roof, 34 feet diameter by 10 feet high in the shell.

General construction.—See previous tank specifications. Plates and angles shall be of the following weights and sizes:

Bottom rectangles	7.32 pounds	Second ring	7.65 pounds
Bottom sketches	7.65 pounds	Roof plates	4.46 pounds
First ring	8.25 pounds	Top angle	¼ in. × 2 in. × 2 in.
Bottom angle	$\frac{5}{16}$ in. × 2½ in. × 2½ in.		

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	
Bottom angle to 1st ring	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	
1st to 2d	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	$\frac{7}{16}$-inch R., 1¾-inch P., D.R.L.
2d		$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.
2d to top angle	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	
Top angle to roof	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	

Location	Miscellaneous
Bottom Rectangles	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.
Bottom sketches	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.
Roof plates	⅜-inch R., 1½-inch P., S.R.L.

Caulking.—All bottom seams and bottom angle shall be caulked inside, shell seams outside, caulking of roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 6-inch suction flange, long hub, located in shell, centered on a line 18 inches above bottom of tank, and 2 feet to right of manhole.

1 6-inch run-down flange, single hub, located in shell, centered on a line 12 inches below top, and 2 feet to right of 6-inch suction flange.

1 3-inch water draw-off flange, long hub, located in shell, centered on a line 8 inches above bottom of tank and 4 feet to right of 6-inch suction flange.

1 2-inch steam fire flange, single hub, located in shell, centered on a line 9 inches below top, and 4 feet to right of 6-inch run-down flange.

Swing pipe.—Each tank shall be furnished with one 6-inch swing pipe. See previous tank specifications.

Manholes.—Each tank shall be provided with two manholes; one 20-inch C. I. manhole in center of first ring, to be provided with $\frac{3}{8}$-inch by 40-inch by 40-inch reinforcing plate at point of attachment; one 20-inch steel plate neck, located on the roof of tank as close to shell as good practice will allow, centered 3 feet to left of side neck. See previous tank specifications.

Ladder.—Each tank shall be provided with a standard steel ladder on the outside, located 3 feet to left of lower manhole.

Roof supports.—Roof shall be of self-supporting globe type, fabricated from eighteen segmental plates of 12-gage or 4.46-pound sheets.

Testing.—Each tank shall be tested when bottom ring is in position, and again upon completion.

Twenty Filling Tanks—600 Barrels

Dimensions.—Each tank shall be of horizontal type, 11 feet diameter by 40 feet long in the shell.

Construction.—Each tank shell shall be made of seven or eight roundabout courses of 8.92-pound best quality tank steel. Heads shall be made in two pieces of 10.2-pound plate best quality pressing steel, formed in conical shape and flanged-in for single row of $\frac{7}{16}$-inch rivets.

Riveting.—All riveting shall be in accordance with the following schedule:

Roundabout seams................. $\frac{7}{16}$-inch R., $1\frac{1}{2}$-inch P., S.R.L.
Horizontal seams.................. $\frac{7}{16}$-inch R., $1\frac{3}{4}$-inch P., D.R.L.

Caulking.—All seams shall be caulked on outside.

Flanges.—Each tank shall be provided with the following flanges, the latter to be of standard light forged steel type known as tank flanges, except steam flanges which will be of special forged-steel construction, with provision made for flare of head, so that axes of flanges shall be parallel to long axis of tank.

1 4-inch suction flange, long hub, located in shell, on opposite side to top manhole, centered on a line 9 inches from one end.
1 3-inch discharge flange, single hub, located in shell, on same line with top manhole, and 1 foot to right of latter.
1 $1\frac{1}{2}$-inch water draw-off flange, single hub, located in shell, on same line as suction flange, but 9 inches from end opposite to latter.
1 2-inch fire steam flange, single hub, located in shell, centered on same line as 3-inch discharge flange, 1 foot to right of latter.
2 1-inch special steam flanges, long hub, located at end adjacent to 4-inch suction flange; one located on a line 12 inches above bottom of tank, and one located on a line 6 inches above bottom; flanges centered 2 feet apart, equidistant from respective sides of shell.

Swing pipe.—Each tank shall be provided with one 4-inch swing pipe, complete with cable chain and attachment hook on inside of top manneck.

Manholes.—Each tank shall be provided with two 18-inch C. I. manholes; one standard light screw cover type, located shell on a line 180° from line of suction flange, centered between ends; one special neck type, cast so that its axis shall be parallel to long axis of tank, located end adjacent to $1\frac{1}{2}$-inch water draw-off flange, and centered 2 feet above bottom of tank.

Two Acid Tamks—125 Barrels

Dimensions.—Each tank shall be of vertical type, tight steel roof, 10 feet diameter by 10 feet high in the shell.

General construction.—See previous tank specifications. Plates and angles shall be of the following weights and sizes:

Bottom rectangles........10.20 pounds	Second ring.............8.92 pounds
Bottom sketches..........10.20 pounds	Roof plates..............7.65 pounds
First ring................10.20 pounds	Top angle....$\frac{5}{16}$-inch by 2½-in. by 2½-in.
Bottom angle, ⅜-inch by 3½-in. by 3½-in.	

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle.	⅝-inch R., 2 -inch P., S.R.L.	
Bottom angle to 1st ring.	⅝-inch R., 2 -inch P., S.R.L.	
1st to 2d..............	⅝-inch R., 2 -inch P., S.R.L.	⅝-inch R., 2¼-inch P., D.R.L.
2d......................		$\frac{7}{16}$-inch R., 1¾-inch P., S.R.L.
2d to top angle.........	$\frac{7}{16}$-inch R., 2¼-inch P., S.R.L.	
Top angle to roof.......	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	

Location	Miscellaneous
Bottom sketches.................	⅝-inch R., 2-inch P., S.R.L.
Roof plates.....................	⅜-inch R., 2-inch P., S.R.L.

Caulking.—All bottom seams and bottom angle shall be caulked inside, shell seams outside, roof seams outside lightly caulked.

Flanges.—Each tank shall be provided with the following flanges, latter to be of standard forged steel type known as boiler flanges, except outlet flange which shall be of special forged steel, and have bottom face turned to seat a 60° conical plug:

1 2-inch discharge flange, single hub, located shell, centered on a line 9 inches below top, and 2 feet to right of 3-inch outlet flange.
1 3-inch special outlet flange, single hub, located bottom of tank outside, 2 feet to right of lower manneck and as close to shell as good practice will allow.

Outlet plug.—Each tank shall be equipped with a 3-inch 60° conical C. I. lead covered outlet plug.

Manholes.—Each tank shall be provided with two manholes; one 20-inch C. I. manhole in center of first ring, latter reinforced by a $\frac{5}{16}$-inch by 40-inch by 40-inch plate at point of attachment; one 20-inch steel plate neck, located roof of tank as close to shell as good practice will allow, centered 3 feet to left of side neck. See previous tank specifications.

Ladder.—Each tank shall be provided with a standard steel ladder on the outside, located 3 feet to left of lower manhole.

Roof supports.—Roof shall be of self-supporting globe type, fabricated from ten segmental plates of 7.65-pound sheets.

Two Acid Blow Cases

Dimensions.—Each case shall be of horizontal type, 3 feet in diameter by 8 feet long in the shell.

Construction.—Each case shell shall be made of one course of 20.4-pound best quality tank steel. Heads shall be made from one plate each of 20.4-pound flange

steel; one plate to be flanged O. D., the other I. D. with extra long and flattened flanging so that the corrosive action of acid around rivets will be reduced to a minimum.

Riveting.—All riveting shall be in accordance with the following schedule:

All seams, ¾-inch R., 2½-inch P., D.R.L.

Caulking.—All seams shall be caulked on outside.

Flanges.—Each case shall be provided with the following flanges, latter to be of heavy standard forged steel type, known as marine flanges:

1 2½-inch outlet flange, located O. D. end, as close to shell as good practice will allow.
1 3-inch inlet flange, located in shell, on a line parallel to long axis of case directly opposite outlet flange, and centered 9 inches from O. D. end.
1 2-inch air flange, located on above line and centered midway between ends.
1 ¾-inch vent flange, located on above line and centered 9 inches from I. D. end.

Testing.—Each case shall be tested under 200-pound hydrostatic pressure.

Two Lye Tanks—125 Barrels

Dimensions.—Each tank shall be of vertical type, tight steel roof, 10 feet diameter by 10 feet high in the shell.

General construction.—See previous tank specifications. Plates and angles shall be of the following weights and sizes:

Bottom sketches	7.65 pounds	Second ring	7.65 pounds
First ring	8.25 pounds	Roof plates	4.46 pounds
Bottom angle	$\frac{5}{16}$-inch by 2½-in. by 2½-in.	Top angle	¼-inch by 2-in. by 2-in.

Riveting.—All riveting shall be in accordance with the following schedule:

Location	Riveting circular seams	Riveting vertical seams
Sketches to bottom angle	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	
Bottom angle to 1st ring	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	
1st to 2d	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	$\frac{7}{16}$-inch R., 1¾-inch P., D.R.L.
2d		$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.
2d to top angle	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	
Top angle to roof	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.	

Location	Miscellaneous
Bottom sketches	$\frac{7}{16}$-inch R., 1½-inch P., S.R.L.
Roof plates	⅜-inch R., 1½-inch P., S.R.L.

Caulking.—All bottom seams and bottom angle shall be caulked inside, shell seams outside, caulking of roof not required.

Flanges.—Each tank shall be provided with the following flanges:

1 3-inch outlet flange, located on bottom of tank, outside, 2 feet to right of manneck and as close to shell as good practice will allow.
2 2-inch discharge flanges, located on shell, centered on a line 9 inches below top, 12 inches and 24 inches to right of 3-inch outlet flange respectively.
1 ¾-inch air flange, located on shell, on line above mentioned, 1 foot to right of second discharge flange.

Manhole.—Each tank shall be provided with one 20-inch steel plate neck, located on the roof of tank as close to shell as good practice will allow. See previous tank specifications.

Ladder.—Each tank shall be provided with a standard steel ladder on the outside, located directly below manhole.

Roof supports.—Roof shall be of self-supporting globe type, fabricated from ten segmental plates of 4.46-pound sheets.

Two Working Tanks—56 Barrels

Dimensions.—Each tank shall be of open vertical type, 10 feet in diameter by 4 feet high in the shell.

General construction.—See previous tank specifications. Plates and angles shall be of the following weights and sizes:

Bottom sketches. . 11.65 pounds	1st ring. . . . . 7.65 pounds
Bottom angle. . . . . 5/16 in. × 2½ in. × 2½ in.	Top angle. . . ¼ in. × 2 in. × 2 in.

Riveting.—All riveting shall be in accordance with the following schedule:

All seams 7/16-inch R., 1½-inch P., S.R.L.

Caulking.—All bottom seams and bottom angle shall be caulked inside, shell seam outside.

Two Working Tanks—500 Gallons

Dimensions.—Each tank shall be of open vertical type, 5 feet diameter by 4 feet high in the shell.

General construction.—Each tank shell shall be constructed of best quality tank steel, bottom to be made from one plate of similar weight material and flanged O. D. for joining to shell, latter to be reinforced at top with angle ring turned out. Plate and angle shall be of the following weight and size:

Plate, 7.65 pounds. Top angle, ¼ inch by 2 inches by 2 inches.

Riveting.—All riveting shall be in accordance with the following schedule:

All seams, 7/16-inch R., 1½-inch P., S.R.L.

Caulking.—All seams shall be caulked on outside.

Two High Pressure Air Tanks—300 Cubic Feet

Dimensions.—Each tank or receiver shall be of horizontal type 5 feet diameter by 15 feet long in the shell.

Construction.—Each receiver shell shall be made of two or three courses 15.30-pound best quality tank steel. Heads shall be made from one plate each of 17.85-pound flange steel; one plate to be flanged O. D., the other I. D., standard construction.

Riveting.—All riveting shall be in accordance with the following schedule:

Roundabout seams, ¾-inch R., 2⅜-inch P., D.R.L.
Horizontal seams, ¾-inch R., 3¼-inch P., T.R.L.

Caulking.—All seams shall be caulked on outside.

Flanges.—Each receiver shall be provided with the following flanges:

1 1-inch draw-off flange, located in shell, centered on a line 9 inches from O. D. end.

2 2½-inch air flanges, located in shell, on a line 180° from 1-inch draw-off flange, each centered 4 feet from respective ends.

Manholes.—Each receiver shall be provided with one 9-inch by 14-inch flanged manhole, complete with manplate, cover, crabs and bolts, located shell on same line as air flanges, centered between.

Testing.—Receivers shall be tested under 150-pound hydrostatic pressure.

General Refining Scheme

The designing of a plant to operate on Lima or similar crude oils, of alkyl-sulphur content, while largely a matter of history at present, involves either the construction of sweetening stills, copper oxide recovery plant, etc., or double capacity treating and

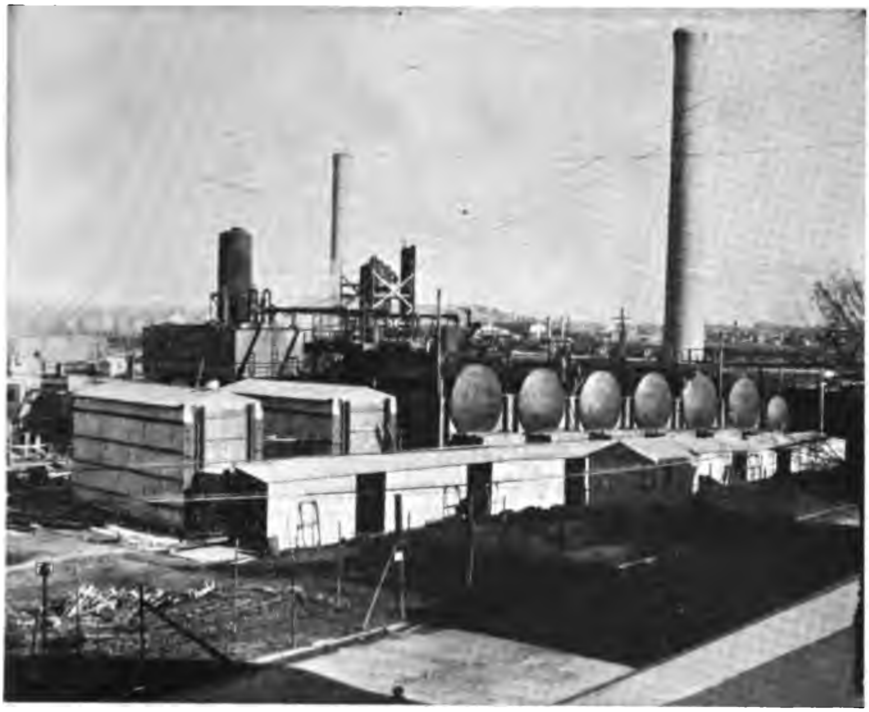


Fig. 15.—Crude and pipe still batteries for refining Mexican petroleum, at Everett, Mass.

rerunning equipment of a special nature. Also it may be said in passing, that the designing of such a plant requires a knowledge of the technology of petroleum not likely to be possessed by the average engineer. Such construction has at least the advantage that it has been worked out to the last detail, and is practically standard for the light-oil process of a Lima plant. The balance of the equipment for the distillation of residuum and the finishing of wax and paraffin oils does not differ materially from that employed on Mid-continent crudes.

Plants that are designed to operate on Texas crude oils offer special problems in topping and in removal of sulphur compounds. They also require additional capacity for the treating of lubricating oils and their subsequent reduction, as well as entirely different equipment for asphalt manufacture. Similarly the California plant design also has its topping problems, in many respects like those of the Mexican refiner. In

addition it considers special treating equipment for its lubricating oils and more especially for its refined kerosene. The details of such special processes and the design of

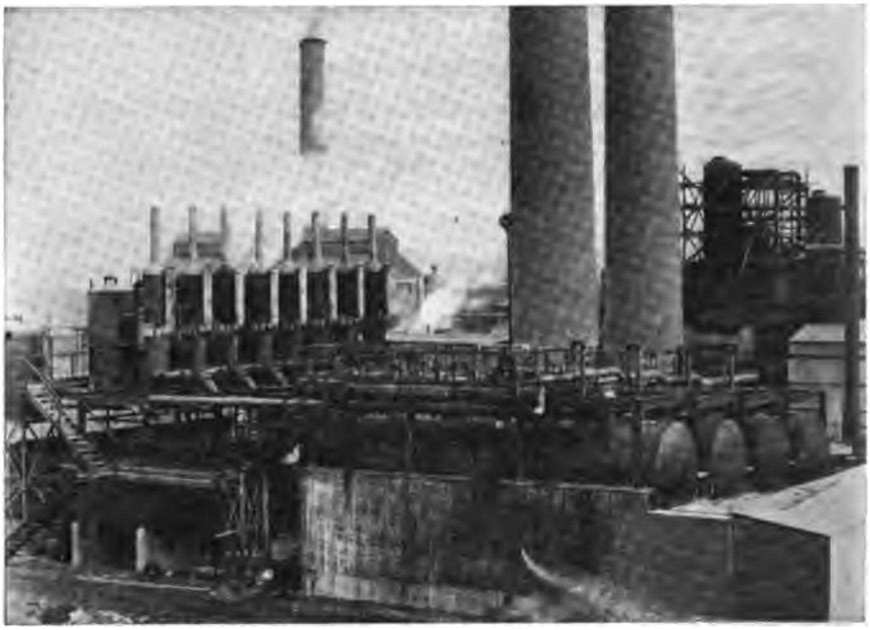


FIG. 16.—Reducing stills for refining Mexican petroleum, at Everett, Mass.

the apparatus are more or less of a secret nature and therefore outside of the scope of a book of this kind. The designs of plants to operate on Mexican crude vary from topping units removing only 2 to 4 per cent of naphtha down to 16 to 18 per cent with

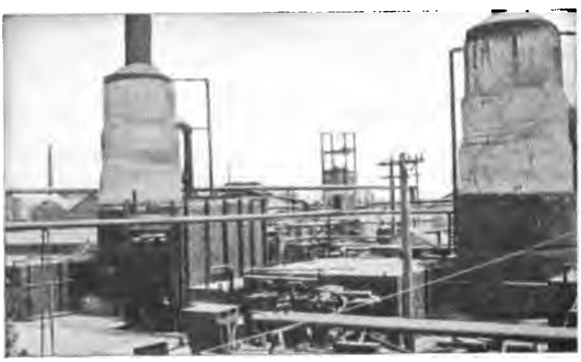


FIG. 17.—General view of pipe retorts and evaporators. Vernon (California), Trumble plant.

the lighter grades. Some of them finish to asphalt, others reduce to coke, making all products. A complete plant of the latter type is illustrated in Figs. 15 and 16. Illustrations of various types of California plant construction is also shown in Fig. 17, with cuts of general layout in Figs. 18, 19 and 20.

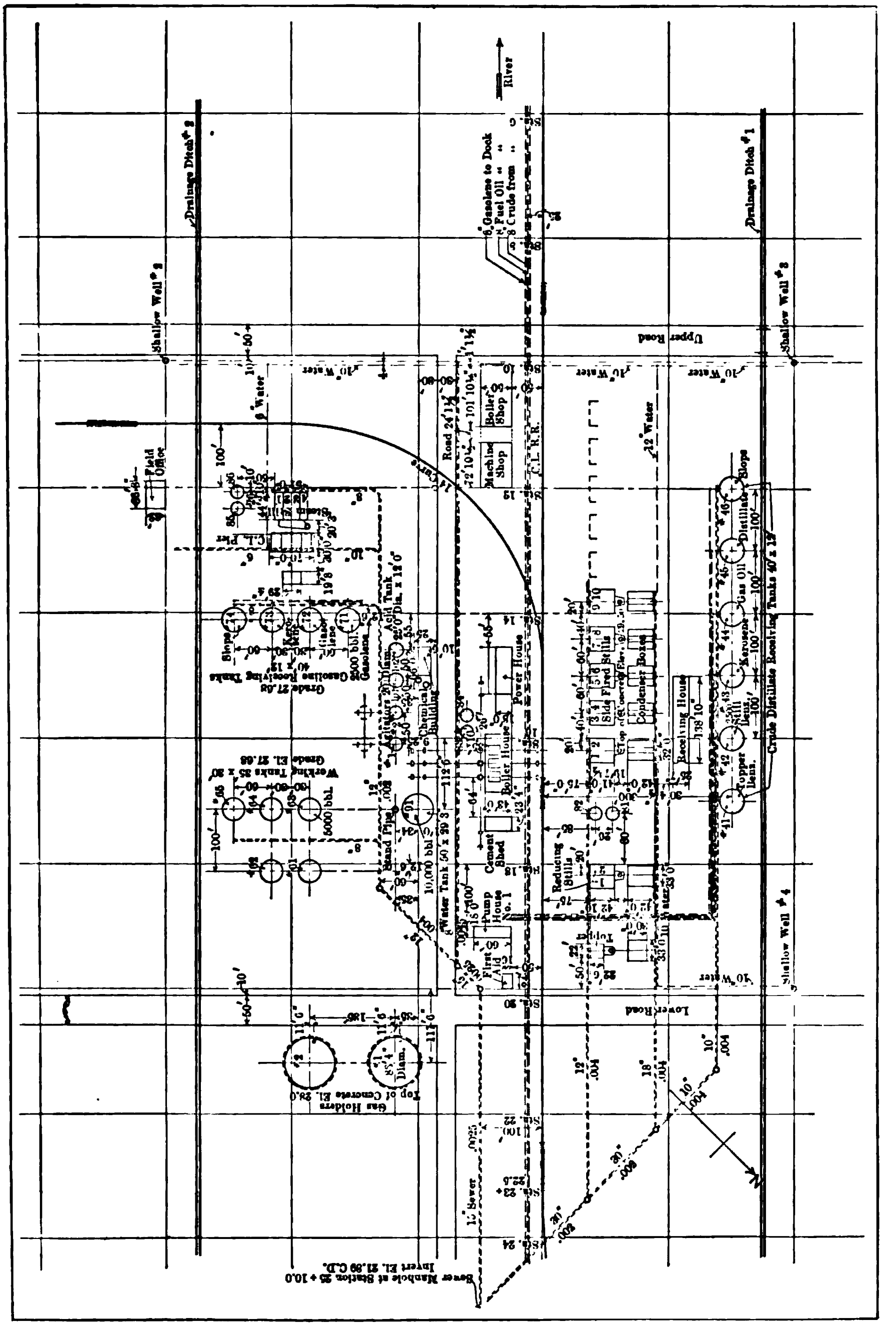


FIG. 18.—Layout of a 10,000 barrel refinery in Louisiana operating on Mexican crude.

The difference in the designs for plants operating on foreign crudes is largely the result of custom and general difference in standards of manufacture and equipment,[1] rather than the requirement of the crude itself for any radically different treatment. On account of cheaper labor, a greater demand for certain by-products and the reduced cost of chemicals, there is a tendency to give greater attention in foreign practice to sludges, waste lyes, etc., than has hitherto been practiced in this country. Such utili-

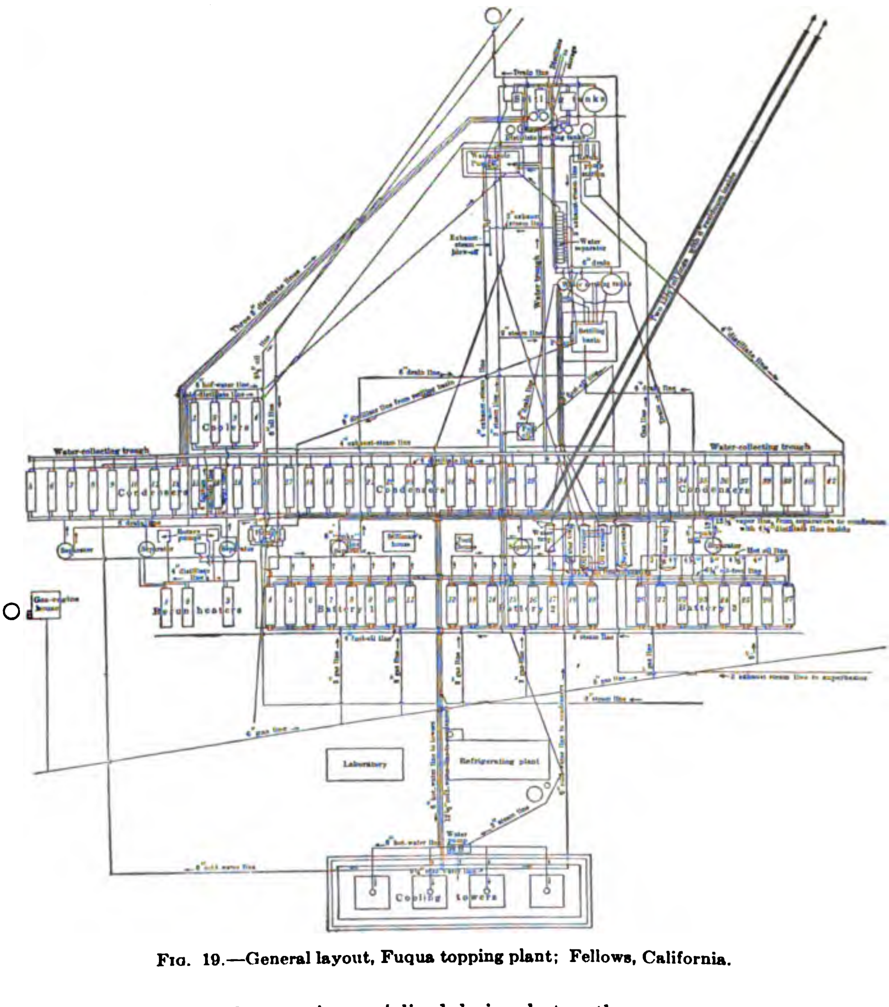


FIG. 19.—General layout, Fuqua topping plant; Fellows, California.

zation of material calls for certain specialized design, but as these are matters primarily of process rather than of engineering, the entire subject of foreign practice will be handled in the chapters on refinery operation. Attention will now be given to more general matters affecting plant design.

Nature of crude delivery.—This topic, intimately connected with that of storage, has a decided effect upon the layout, particularly if the crude is to be received by tank-

[1] A notable exception is the Edeleanu process applied to Rumanian crude. (Fig. 161, page 393.)

car or barge delivery. If a railroad proposition, intervals of delay due to embargoes, strikes, etc., must be considered, as well as present routing, and possible alternatives. In arriving at a minimum crude tankage, due weight to such matters as loading facilities at the point of origin, general condition of motive power and roadbed of shipping road, the number of junction points passed and whether the road delivers crude to one refiner or several should be given. While it is obvious that no fixed rule can apply, a plant re-

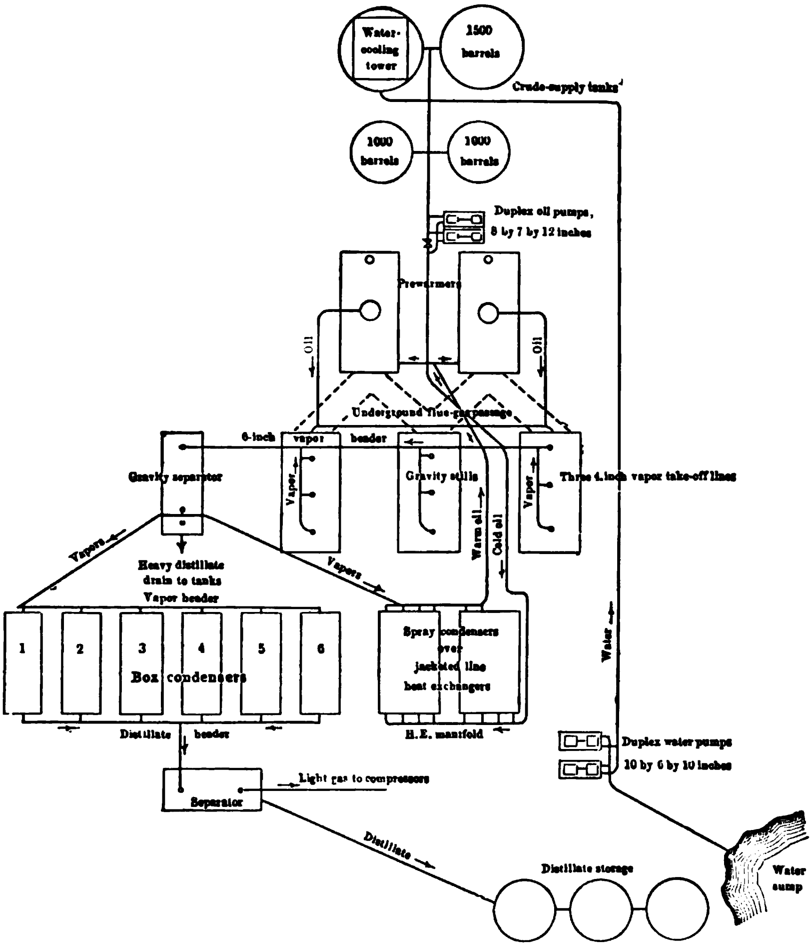


FIG. 20.—General arrangement of Brown-Pickering topping plant; Fullerton, California.

ceiving its crude supply by tank cars, especially from any considerable distance, should possess at least one month's, or better, two month's crude storage. When the supply is received by oil barge or tank steamer, the design will include, in addition to tankage requirements, adequate wharfage as well. In a large plant provision is frequently made for the dockage of two steamers at the same time. Such construction runs into considerable extra initial cost but is justifiable when any possible delay to tankers is considered. As in the case of railroad deliveries, many factors have their bearing

on determining minimum tankage requirements, as well as actual construction of wharfage. These factors include loading facilities at point of origin, the question of low water or sand bars, the navigability of river or port at all times, whether steamers are owned or regularly chartered, etc., etc.; Wharfage facilities vary from a small floating dock with cluster piles as mooring points, to permanently built docks of 600 to 1000 feet in length, protected by drift guard piles from 100 to 500 feet on the upper river batture. Again, while there can be no fixed rule, experience has generally demonstrated that the initial crude tankage and wharfage, as usually constructed for plants receiving their crude supply by tank steamer, has proved inadequate. Therefore a two months' crude storage as a minimum, with a wharfage equal to the forced demand should be constructed at the inception of the plant. Assuming regularity of production, crude deliveries by pipe-line can usually be counted upon, with due allowance for breaks at rivers in flood period, as being regular and requiring a minimum storage. One month's supply is amply sufficient to insure continuous plant operation. Other important reasons, however, entirely independent of the method of delivery, often warrant crude storage units far in excess of the minima mentioned. Such reasons are discussed under the topic of storage.

Special refining units.—Under this heading, in its effect on plant design, are included the apparatus and equipment incidental to cracking processes, acid recovery plants, special chemical recoveries from by-products, etc. A special division of this book is given over to a description of cracking processes, and the subject of acid recovery is considered in a subsequent section. But, in general, special processes are either in a stage of development or are operated more or less as secret methods, so that the details of construction of the apparatus involved cannot be discussed in a book of this nature, beyond stating that special provision is made for their installation, generally apart and frequently quite remote from the general part of the refinery.

Storage.—The last item to be discussed in its effect on plant design is yard storage as distinguished from field storage. In providing for the latter the designer generally deals exclusively with the crude which belongs to the producing end of the business. Yard storage obviously involves not only crude, but intermediates, and all refined products as well, and varies, as previously intimated, from a few days' running capacity to that of months, in well-proportioned plants. Some of the factors affecting crude storage alone have already been discussed under the topic of nature of delivery. Other factors involving all yard storage are the amount and nature of ground available, nearness to markets, freedom of locality from prevailing electric storms, the extent to which refining is practiced, and the general sales policy of the company.

The amount of ground available limits and modifies to a great extent the layout of refinery storage, as certain minimum distances between tanks and adjacent property must be maintained to secure the lowest or most favorable insurance rates. A fairly clear idea of the amount of storage contemplated should be possessed before the site is determined lest it be discovered that the plant site is too small to install the desired number of tanks except at increased insurance cost. An excessive cost of land may, however, warrant such construction, but where plenty of land is available the following table will be of benefit as insuring a very favorable if not the minimum insurance rate.

The contents of tankage bears a certain relation to credits, as will be mentioned in a subsequent section.[1] While this and other modifying regulations may cause a slight increase in rates in certain instances, this difference is generally so slight as not to warrant a much greater spacing distance than noted in the preceding table. This is especially the case in the matter of smaller tankage such as run-down tanks, where a greater spacing than 25 feet would render plant operation more or less impracticable.

[1] See pages 422 to 425.

Tank Spacing Table for Favorable Insurance Rates

Minimum distances

Capacity of tanks, barrels	Distance between, feet *
74,000	350
55,000	350
37,500	300
20,000	200
10,000	200
5,000	150
2,500	50
2,000	50
1,500	25
1,000	25

* In field storage it is generally customary to space 74,000- and 55,000-barrel tanks on 500-foot centers.

In considering the effect of tankage layout on design, it is also desirable to maintain the following distances from other departments of the refinery:

40 feet from any brick, stone, concrete or tile building.
60 feet from any frame, iron-sheathed or brick-veneer building.
380 feet from any compression or absorption gasoline system.

The following table, applying to steel tanks above ground, gives an idea of the requirements necessary to secure the lowest insurance rate in the state of Illinois.

Tank Spacing Table for Minimum Insurance Rate in Illinois

Capacity of tank, gallons	Capacity of tank in barrels of approx. 42 gallons	Minimum distance to property line or nearest building, feet
3,000 or less	70	20
21,000 or less	500	25
31,000 or less	700	30
45,000 or less	1,000	40
64,000 or less	1,500	50
80,000 or less	1,900	60
128,000 or less	3,000	75
200,000 or less	4,700	85
266,000 or less	6,300	100
400,000 or less	9,500	150
666,000 or less	15,800	250
1,333,000 or less	31,700	300
2,666,000 or less	61,000	350

Certain authorities advocate, on all tanks above 5,000 barrels, a spacing equal to two and one-half times the diameter of the tank, while others by a standard system of dike measurements insure adequate distances.

If underground tankage is installed (this is ordinarily held to mean concrete tankage, although brick set in concrete has sometimes been successfully used), the spacing limits previously mentioned are no longer followed. But in laying out a plant it must be ascertained that the nature of the soil is such as to permit the construction of such tankage, without the danger of settling, with attendant cracking of walls and leakage of oil. Such construction, for instance, is practically impossible in the lower Mississippi territory, except at prohibitive cost.

Underground tanks, while possessing advantages from the point of view of fire risk, are not readily cleaned, because water and sediment must be pumped out, rather than drawn off by gravity, and on account of the generally shallow construction of these tanks considerable volume is lost when even a few inches of water or sediment remains in the tank. Moreover the strapping of such tankage is not such a simple proposition as that of the steel tank, and the present cost offers no great inducement for construction. All in all, considering their inflexibility, concrete underground tanks are not so generally adaptable for all-round refinery purposes as the standard steel unit. Where the cost of land is excessive, where it is desired to store a maximum amount of crude, or, where a few products are produced with little likelihood of change in specifications, the concrete tank (cost considered) has obviously its advantages. However, it will probably always remain a field unit of storage rather than an important factor in general refinery practice.

Certain peculiar soil formations have allowed the construction of perfectly tight tanks by simple excavation to a desired depth, and protection from caving walls has been secured merely by laying 1-inch by 10-inch boards on edge, one upon the other until the surface of ground was reached. Such a type of tank is only possible in deep strata of clay; the underground tanks in blue clay of the Paragon Refining Company at Toledo, Ohio, and of the Imperial Oil Company at Sarnia, Ontario, being typical examples. Where such types of tanks are protected by concrete roofs, they are practically the equal of the all-concrete tank in both its advantages and disadvantages, their spacing being dependent on depth and pressure developed. It is usually customary to reduce the diameter of such tanks at varying intervals of depth to afford thicker intervening walls, corresponding to the increased pressure of fluid, and thus allow a closer spacing which would otherwise be impossible.

In determining the size and number of storage tanks proportionate to a given refining capacity, certain empirical considerations, custom and general sales policy govern, independent of the question of available plant-size area. Thus the units of 5000 and 10,000 barrels listed in the typical skimming plant specifications appropriate for plants of this size would be replaced by 10,000-, 20,000- and perhaps 55,000-barrel tanks as main storage units in plants of 5,000 to 10,000 barrels daily refining capacity. Larger plants usually erect 30,000-, 37,500-, 55,000-, and in some instances 74,000-barrel tanks for their reserves, and 10,000-barrel tanks as working units. The dimensions of such tankage usually conform to well-established relations between diameter and height. The appended table will enable the engineer to allow proper distances in plant layout, as well as to compute pressure developed per square-foot of bearing surface. The latter is exceedingly important in sites where the soil is of weak supporting power.

Where the ground is limited in area and a maximum number of tanks is desired and they are spaced to secure minimum insurance rates, tanks 40 feet in height are sometimes erected. Their cost, except in large diameters, is usually excessive, due not only to increase of weight of metal necessary on account of increased fluid pressure,

Dimensions and Weights of Standard Steel Tankage *

Capacity, barrels of 42 gals.	Diameter.		Height.		Cone roof weight in Pounds	Dome roof weight in Pounds
	feet	inches	feet	inches		
500	20		10		11,800	12,100
1,000	20		21	3½	18,200	18,500
2,000	25		27	3	31,200	30,500
2,500	25		30		33,900	33,300
3,500	30		30		42,500	41,300
5,000	35		30		52,000	49,800
6,000	38		30		59,100	56,400
10,000	50		29	3	88,800	87,000
15,000	60		30		120,000	.....
20,000	70		29	3	159,300	.....
25,000	78		30		198,000	.....
37,500	95	6	29	9	281,000	.....
55,000	114	6	30	2¼	415,000	.....
65,000	114	6	34	9	475,000	.....

* Dimensions and weights are according to the Graver Corporation, E. Chicago, Ind.

but to additional strength that must be imparted to withstand the extra wind stresses developed by the added height. Such a condition is more often met in plants located near industrial centers where the manufacture of a varied line of products is contemplated. Finished storage tankage in such instances is less in individual capacity than in plants refining to a few grades, but it obviously gives the engineer more concern in design. It may likewise be desired to store crude in large quantities at the refinery site, on account of high construction costs of field tankage or undesirability of maintaining crude stocks at points distant from central control. Such factors have an important bearing on the relation of storage capacity to plant design, and are a part of the general business policy, which may further include marketing through company-owned filling stations or dependable yearly contracts, and thus require less finished storage than would be needed by a concern electing to forecast the markets.

Changing conditions and uses for products, such as the introduction of kerosene-burning farm tractors, and the increased use of the automobile in winter have done much to stabilize demand, so that a hard-and-fast rule in the matter of storage for all plants is an impossibility. Not only must the physical question of available land enter into a decision, but a thorough study of market conditions in conjunction with the general business policy of the company must govern to a great extent. In general the larger the reserve capacity, the sounder the foundation for ultimate success. While immediately available capital does not always admit the erection of the complete number of storage tanks desired, provision should always be made for future growth, for while increased running capacity may often be effected by slight changes in process, minor adjustments, etc., storage capacity can only be increased by the erection of tanks, and tanks require land. The illustrations in Figs. 21 and 22 show various types of refinery yard storage.

Buildings.—In their effect on general plant design, refinery structures may be classified as follows:

(*a*) Buildings relating to the basic process, operation, etc.
(*b*) Buildings relating to shipping, compounding, etc.
(*c*) Buildings relating to housing of employees.
(*d*) Buildings of administration.

Fig. 21.—Refinery storage and working tanks.

Fig. 22.—Refinery storage and working tanks.

Under the first group will naturally be included pump house, receiving house, boiler house, repair shop, warehouse, etc., for small plants, and such additional units as wax plant, sweating building, filter house, earth-retort building, etc., for the larger plants which refine to more varied products. The number and size of such buildings will obviously be proportional to the quantity of crude refined and to the processes employed.

Under classification (*b*) will fall such structures as the shipping building, cooperage building, oil warehouse, grease plant, etc., their number and size being dependent on the quantity of crude refined, the products manufactured or compounded and the general business sales policy of the company.

Group (*c*) includes wash rooms, bunk and mess houses, residence dwellings, etc. In some of the larger plants, remote or inaccessible from centers of population, school buildings and even churches are built upon refinery property. It is obvious that local living conditions, in conjunction with the views of the management on such projects will govern the number and type of this class of structures, although it may be said, in passing, that certain state laws founded on sanitation measures, more rigid insurance rulings and doubtless in some instances purely humanitarian motives have done much to improve this class of buildings.

The last division (*d*) includes the office, laboratory, etc. The size of such structures varies from a single-room shack, comprising both departments in some of the smaller skimming plants, to two-story or higher buildings in many of the larger refineries. If the general offices of the company are located at the plant, the office becomes a decidedly important structure, and its location must be given serious consideration in the design of the plant. It should further be noted that in such instances the number of products made and the plan of distribution govern the size of the building required, rather than the absolute quantity of oil run. Thus a Pennsylvania plant refining 10,000 barrels of crude per month, doing a general compounding business, and disposing of its output principally through barrels and cans in small lots, may easily require twenty times the office space of a Mid-Continent plant running the same quantity of oil per day, but marketing its production through export channels and large sales. The size of the laboratory, also dependent upon the number and nature of the products manufactured, will be further controlled by the general policy of the company towards investigating problems of the trade and by its attitude toward research in general. The present tendency in all plants is to give greater prominence to laboratory control than in the past.

In actual plant design, it should always be borne in mind that buildings falling under classifications (*a*) and (*b*) should be erected of fireproof construction, not only to secure a low insurance rate, but to guarantee continuous operation of the plant. This is especially true with class (*a*) buildings. There is little excuse for not following the rules recommended by insurance rating bureaus in the erection of such structures. Where rigid initial economy is imperative, certain class (*b*) structures, such as cooperage building, shipping building, etc., may be built of frame construction, corrugated clad, with solid cement floor, if sufficiently removed from tanks, stills, etc. However, such construction is far from ideal.

In class (*c*) buildings, wash rooms and locker rooms should invariably be of fireproof construction. As but few companies can stand such investment for dwelling cottages, mess rooms, etc., it is usually customary to locate the latter class of structures at a considerable distance from the nearest refinery equipment, and build them of ordinary frame construction.

Administrative buildings, at least in the case of laboratories, should be of fireproof construction. Local conditions should govern the office design. Where a minimum amount of testing is required, a fireproof laboratory may be installed at small expense under a condenser box. In many plants where the general office is not located at the refinery, a frame building provided with a fireproof vault will make a very satisfactory works office, if located sufficiently far from tanks and stills. Any extensive experimental laboratory control should invariably be undertaken in a fireproof building detached from other equipment. Similarly a large general office building with pre-

sumably valuable records and office furnishings would also justify only fireproof construction.

General.—In the spacing of the various units, care should always be exercised, not only to maintain distances advocated by insurance rating bureaus, but to align buildings, tanks, stills, etc., so as to afford free passages or roads connecting the different departments. Such roadways should vary from 20 to 40 feet in width, depending on the size of the units involved, land available, etc. The primary source of power or steam generating units should be completely removed from any source of danger from fire, such as stills, tanks, etc. As far as is practical, the grouping of the latter should be so arranged (independent of spacing distance) as to secure a minimum insurance rating, considering the contents of the tanks.[1] The office building at the works should be near the entrance of the plant, some 25 to 50 feet or more back of the property line, and at least 100 feet, where distance permits, from any tank, still, etc. Such a distance, while exceeding minimum insurance requirements, is advisable for pleasant working conditions. In short the aim of the practical designer should be to lay out a plant so as to obtain the minimum insurance rate, but at the same time not to sacrifice operating efficiency and reduce capacity by reason of any slight exposure charge. The effect on insurance rates of desirable spacing between all steel tanks has already been discussed.[2] The table below gives minimum spacing distances for both steel and wood-top tanks, as well as stills and other refinery equipment. The layout on page 22, Fig. 13, also gives an excellent idea of the application of such rules to practical design. The separation of stills in blocks, the grouping of run-down tanks apart from agitators, the separation of fuel tanks from those of crude and light-oil storage, as well as the broad roadways between departments are all clearly discernible.

EXPOSURE TABLE

Minimum distances

Tanks

From buildings:

Small [3]	Normal	Large
25 feet	50 feet	100 feet

From tanks:

5000 barrels or less [4]	25 feet
5001 barrels to 10,000	50 feet
Over 10,000 barrels	200 feet

From railroad:

All tanks	75 feet

[1] See Kansas Rating Bureau, Classification of Oil.

[2] See p. 85.

[3] Square feet of floor area governs classification of size of buildings as follows:

Small: Under 750 square feet.
Normal: 751–8000 square feet.
Large: Over 8000 square feet.

[4] All tanks not separated by at least 25 feet of clear space, or any tank of wood, or any tank exceeding 5000 barrels capacity must be included in this group. Acid, alkali and water tanks are considered as clear space. Not more than two oil-tanks of 100 barrels capacity or less may be similarly disregarded when in a space between larger tanks.

Oil stills

From tar stills:

All fire-heated stills .... 25 feet

From steam stills:

All fire-heated stills .... 25 feet

From tanks:

All fire-heated stills ....100 feet

From agitators:

All fire-heated stills ....100 feet

Agitators

From tanks:

Same spacing required as tanks.

From note 3, page 90, it will readily be seen that carelessness in spacing may inadvertently cause a group of relatively small tanks, run-down tanks for instance, to be classified not as individual units of 500 barrels, but as a group in the 5000-barrel class, thus raising insurance rates 16⅔ per cent. Such group classification may, for instance, require a greater minimum distance than actually exists, between agitators or stills and the nearest run-down tank, resulting in a second increase in rate. As a parting caution in general plant design, the engineer is advised to familiarize himself with the underlying principles of fire-protective engineering; he should possess a knowledge of general construction as modified by process requirements and other correlated data.

III. STANDARD APPARATUS DESIGN

The design of standard refinery apparatus has already been more or less empirically treated in the preceding pages devoted to general specifications, and an attempt will now be made to cover the subject in greater detail. With this object in view, the following classification is suggested, the author disclaiming all intent of finality in what should be included as standard apparatus. Only the more important generally recognized refinery equipment is listed.

Standard Refining Apparatus

(a) Tanks:
1. Run-down and bleachers.
2. Working.
3. Storage
4. Miscellaneous.

(b) Stills:
1. Crude stills.
2. Rerunning stills.
3. Reducing stills.
4. Coking stills.
5. Steam stills.

(c) Condensers for:
1. Crude and rerunning stills.
2. Reducing and steam stills.
3. Coking stills.
4. Exchangers.

(*d*) Towers for:
   1. Crude and rerunning stills.
   2. Reducing stills.
   3. Steam stills.

(*e*) Agitators:
   1. Light oil.
   2. Lubricating oil.
   3. Tar.

(*f*) Boilers:
   1. Return tubular.
   2. Water tube.
   3. Marine.

(*g*) Wax-plant equipment:
   1. Refrigerating units.
   2. Chillers.
   3. Pressers.
   4. Sweat pans.

(*h*) Filter-house equipment:
   1. Filters.
   2. Conveying machinery.
   3. Revivifying apparatus.

(*i*) Pumps:
   1. Steam.
   2. Power.

Tanks.—Steel tank standards differ considerably among various manufacturers, not only in dimensions necessary to attain a given capacity, but in weight of plate, rivets, etc., even where dimensions are practically the same. The following table represents the extremes of seven well-known firms, as regards differences in heights and diameters.

Nominal capacity, barrels	Diameter				Height			
	Min.		Max.		Max.		Min.	
	feet	inches	feet	inches	feet	inches	feet	inches
74,000	114	6	114	6	40	0	40	0
65,000	114	0	114	0	34	9	34	9
55,000	114	0	114	7	30	4	30	1¾
37,500	94	0	95	6	30	0	29	9
30,000	85	0	86	0	30	3½	30	0
20,000	77	0	85	0	30	0	25	0
10,000	49	7	55	0	30	0	25	4
5,000	35	0	43	0	35	0	20	0
2,500	25	0	30	0	30	0	20	0
1,000	20	0	22	0	21	3½	15	0
500	20	0	20	0	10	2¾	10	0

Differences in plate weight are naturally to be expected with varying diameters, hence the purchaser if unfamiliar with engineering principles should compare tanks of approximately equal dimensions. In the long run there is little economy in the purchase of light-weight tanks for general refinery purposes, such as run-down tanks, bleachers, or yard storage, or under any conditions of service where free steam, heavy moisture or corrosive sulphur gases are likely to be evolved. Kerosene, lubricants, and wax may be handled in somewhat lighter tankage than is required for other refinery products, although such economy is often questionable. While no fixed rule can be given for all conditions of service, the following table is offered as a guide in construction. Serviceable, tight tanks have been built, using plate of minimum weight specified in the upper rings or the bottom. However, the second figure given is to be preferred. Reference to the general tank specifications already furnished will show either that they comply with the preferred weights in the schedule below, or that they are of heavier design.

Diameter, feet	Height, feet	Minimum weight of plate allowable, pounds	Minimum weight of plate recommended, pounds
Above 40	25 to 30	8.25	8.25
30 to 40	20 to 25	7.65	8.25
20 to 30	20 to 25	7.32	7.65
Under 20	15 to 20	7.32	7.65

The selection of suitable plate does not alone constitute a tight, serviceable tank, for the question of proper riveting plays a very important part. While the laws of rivets are well known, different manufacturers make different allowances for wind pressure and the effect of corrosion on the life of a tank. As a result some use a double row of rivets, others a triple, and some a single row. There can obviously be no fixed rule in such a matter, however, the tank specifications previously given follow the best standard practice. One well-known builder of tanks,[1] with facilities for turning out a complete 55,000-barrel tank every eight hours uses the following rivet-spacing table:

Diameter of rivets, inch	S. R. L., P. inches	D. R. L., P. inches	T. R. L., P. inches	Distance between rows, inches
$\frac{7}{16}$	$1\frac{1}{2}$	$1\frac{3}{4}$	..	$1\frac{1}{8}$
$\frac{1}{2}$	..	$1\frac{3}{4}$	..	$1\frac{1}{4}$
$\frac{5}{8}$	2	$2\frac{1}{4}$	..	$1\frac{1}{2}$
$\frac{3}{4}$	$2\frac{1}{4}$	..	3	$1\frac{7}{8}$

The actual efficiency of the above schedule of riveting based on A.S.M.E. code would be as follows:

[1] Kansas City Structural Steel Company, Kansas City, Missouri.

Diameter of rivets, inch	Weight of plate, pounds	Per cent efficiency, S.R.L.	Per cent efficiency, D.R.L.	Per cent efficiency, T.R.L.
½	7.65	60.9		
	8.25	60.9		
	8.92	60.9		
⅝	10.20	60.7	69.5	
	11.47	60.3	69.5	
¾	12.75	58.9		77.0
	15.30	58.9		76.0
	20.40	57.6		75.0

Apart from the weight of the plate and proper riveting the angle rings must also be properly proportioned. The following tables of standards, kindly furnished by the Riter-Conley Manufacturing Company, Pittsburg, Pa., show the proper sizes of the same, as well a as complete condensed schedule of general tank specifications.

TANKAGE DIMENSIONS AND SPECIFICATIONS

Nominal capacity in 42-gallon barrels	500	1000	2000	2500	3000	5000	10,000
Diameter of tank in feet.........	20′ 0″	22′ 0″	30′ 0″	30′ 0″	30′ 0″	40′ 0″	55′ 0″
Height of tank in feet...........	10′ 2¾″	15′ 0″	16′ 0″	20′ 0″	24′ 0″	22′ 6″	25′ 3¾″
Number of rings in shell.........	2	3	3	4	5	5	5
Weight of first ring.............	7.65	8.28	8.28	8.28	8.92	10.20	10.20
Weight of second ring...........	7.65	8.28	7.65	8.28	8.92	9.55	9.55
Weight of third ring............	....	8.28	7.65	7.65	8.28	8.92	8.92
Weight of fourth ring...........	....	....	....	7.65	8.28	8.28	8.28
Weight of fifth ring............	....	....	....	....	8.28	8.28	8.28
Weight of bottom..............	7.65	8.28	8.28	8.28	8.28	8.28	8.28
Size of bottom angle ring, inches	¼×2½ 2½	5/16×2½ 2½	⅜×2½ 2½	5/16×2½ 2½	5/16×2½ 2½	⅜×3 3	⅜×3 3
Size of top angle ring, inches.....	¼×2½ 2½	5/16×2½ 2½	5/16×2½ 2½	5/16×2½ 2½	5/16×2½ 2½	5/16×2½ 2½	⅜×3 3
Weight of sheets for light nailed roof	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Weight of sheets for tight steel roof..........................	5.10	5.10	5.10	5.10	5.10	5.10	5.10

Nominal capacity in 42-gallon barrels	15,000	20,000	25,000	30,000	35,000	37,500	55,000
Diameter of tank in feet.........	66′ 0″	77′ 0″	85′ 0″	85′ 0″	95′ 5½″	94′ 6″	114′ 7″
Height of tank in feet...........	25′ 0″	25′ 0″	25′ 6″	30′ 5½″	28′ 7½″	30′ 6″	30′ 4″
Number of rings in shell.........	5	5	5	6	6	6	6
Weight of first ring.............	10.83	12.75	13.87	15.50	18.70	17.34	22.00
Weight of second ring...........	10.20	11.47	12.24	13.87	15.45	15.50	18.50
Weight of third ring............	9.56	10.20	11.58	12.24	13.82	12.24	15.00
Weight of fourth ring...........	8.92	8.92	9.71	11.58	10.53	11.59	12.00
Weight of fifth ring............	8.28	8.28	8.28	9.71	9.68	9.71	10.20
Weight of sixth ring............	....	....	....	8.28	8.28	8.28	8.28
Weight of bottom..............	8.28	8.28	8.28	8.28	8.28	8.28	8.28
Size of bottom angle ring, inches..	⅜×3½ 3½	½×3½ 3½	⅜×4 4	⅜×4 4	⅜×4 4	⅜×4 4	⅜×4 4
Size of top angle ring, inches.....	5/16×2½ 2½	5/16×2½ 2½	⅜×2½ 2½	⅜×2½ 2½	⅜×2½ 2½	⅜×2½ 2½	⅜×2½ 2½
Weight of sheets for light nailed roof	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Weight of sheets for tight steel roof........................	5.47	5.47	5.47	5.47	5.47	5.47	5.47

Detailed specifications for steel tankage have been given at length in the preceding pages and need not be considered again in this chapter. Occasionally, however, certain corrosive sulphur-bearing distillates make a steel roof tank inadvisable. A typical set of wood roof specifications for a 55,000-barrel tank is therefore given below.

Standard Wood Roof Specifications for 55,000 Barrels

Tank.—Roof frame shall consist of sixty-one 6-inch by 6-inch best yellow pine timber posts with 5-inch by 14-inch plates, supporting 2-inch by 18-inch rafters. The roof proper shall consist of 1-inch sheathing of No. 1 quality yellow pine, sheathing

FIG. 23.—Water-top roof tanks.

boards to be covered with 22-gage black sheet steel, properly laid and closely nailed on 4-inch laps.

A variation in this construction, which is used with excellent results by one of the larger companies consists in applying galvanized iron sheets instead of black plates, soldering all seams, and applying around the edge of the roof a strip of 6-oz. sheet lead approximately 20 inches wide. The lead is caulked to the top angle and soldered to the roof sheets, a cross-section appearing as an inverted U. Such construction forms a roof as tight, if not tighter, than the average steel design and greatly cuts down evaporation losses and lowers fire risk.

Another type of roof used to a considerable extent, especially in smaller tanks is the so-called water-top roof. This consists simply of a flat-top roof supported by a series of I-beams and caulked to a supporting angle ring which is riveted on the inside

of the shell, the top of the roof being usually 4 inches to 6 inches below top of shell. Such construction is illustrated in Fig. 23, by the six flat-top tanks in the right-hand foreground. The remaining tanks shown are of self-supporting globe or the umbrella type of roof. The details of a 74,000-barrel tank as shown in Figs. 24 and 25

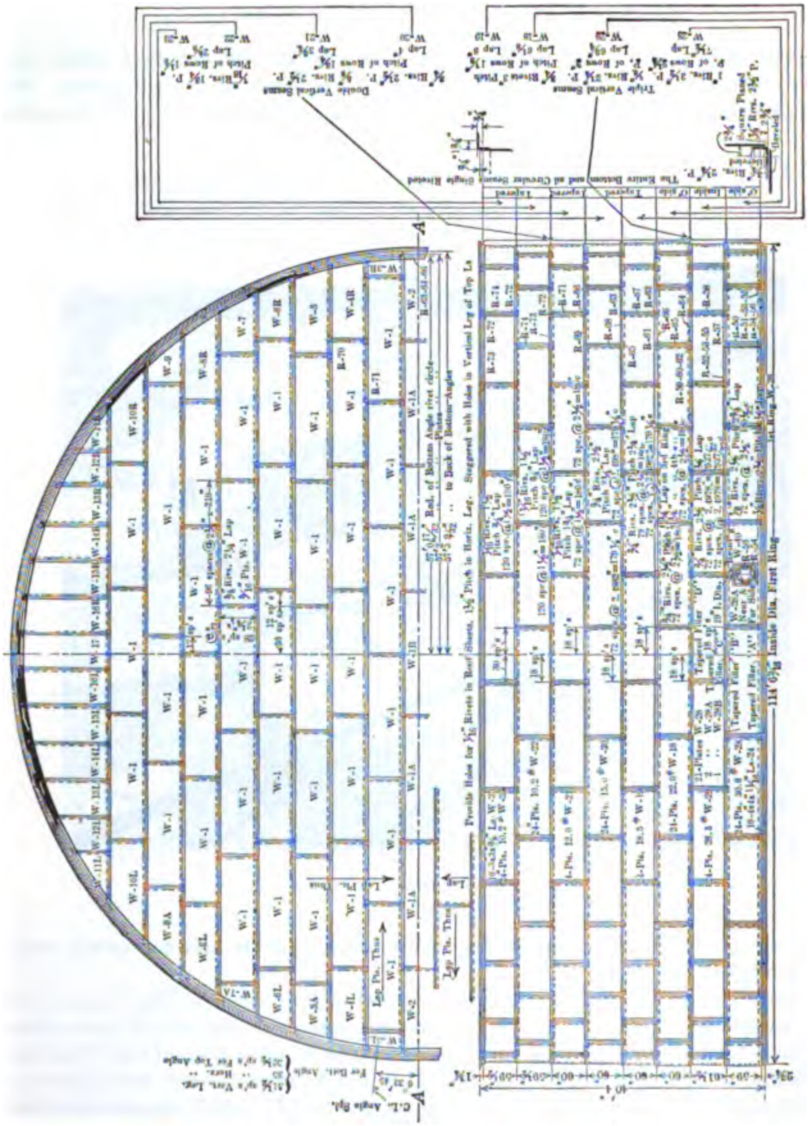
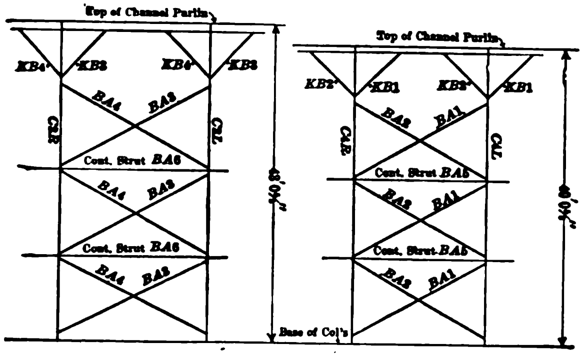


FIG. 24.—A 74,000-barrel tank 114 feet 7 inches by 40 feet 4 inches.

may be accepted as typical of storage tanks of 30,000 barrels and upward capacity. The details of the 10,000-barrel storage tank are shown in Fig. 26. In general, rundown tanks and bleachers should not be over 10 feet high, nor working and storage tanks over 30 or 35 feet for practical use.



Column bracing looking from center of tank

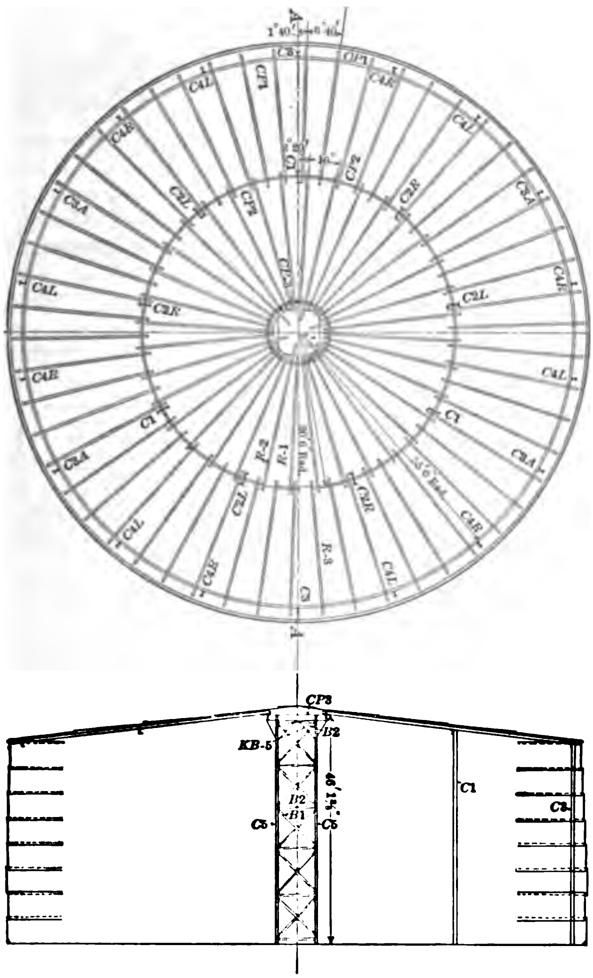


Fig. 25.—Roof support details for a 74,000-barrel tank.

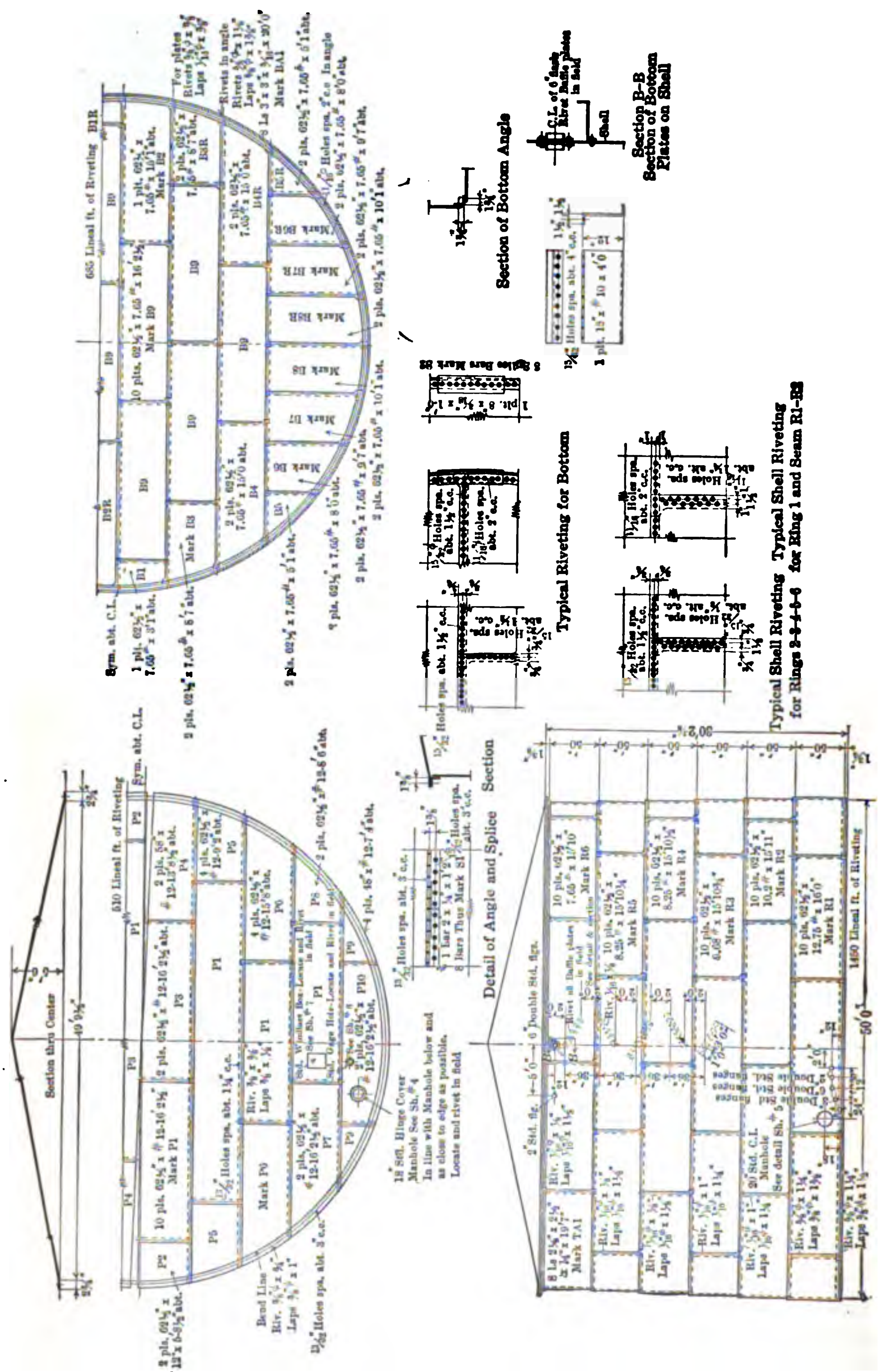


FIG. 26.—A 10,000-barrel tank, 50 feet by 30 feet.

To design a vertical cylindrical tank for maximum capacity with minimum surface, the diameter must equal the height. The following formula is applicable:

$$C = \frac{D^3 \text{ or } H^3}{7.145}$$

where C = capacity in 42-gallon barrels;
D = diameter in feet = H;
H = height in feet = D.

Applying the above to the limiting height for practical use (i.e., 35 feet) a tank of 6006 barrels would have the largest capacity possible. In actual practice this formula is only generally used for diameters of 20 to 35 feet inclusive.

In general the construction of vertical tanks has been brought to a high point of perfection by the leading manufacturers, especially considering the stresses as developed within. In the larger units however, there is probably some ground for criticism in certain types of roof construction as regards ability to withstand high winds. Therefore, in localities where storms of high velocity are prevalent, the so-called sand-line bracing system is recommended. This consists briefly of stringing ⅜-inch flexible steel cables, preferably on radial lines 90° apart, from the ring about the center post 10 feet above the bottom of the tank, to the through-going eye-bolts, located on the shell in the same horizontal plane; then repeating the bracing on a 20-foot level on radii halfway between the former, thus dividing the circumference into staggered 45° segments. With wood-roof tanks a third set of tension cables fastened to the top angle may be effectively used. All cables are provided with turnbuckles, so that a uniform tension may be produced on all lines, and necessary adjustments made from time to time. The term sand-line is derived from the fact that discarded sand-lines from drilling rigs were originally employed. Their use, however, for this purpose is not recommended on account of the probability that they are weakened and worn.

In the general specifications in the preceding pages it will be noted that under caulking, roof seams were not required. While 10-, 11-, and 12-gage plate (the usual tight-roof weights) can be successfully caulked, the average workman in this class of construction is apt to do as much harm as good. If 10-gage plate is riveted with ⅜-inch rivets on 2-inch centers, and 12-gage plate with 7/16-inch rivets on 1½-inch centers, a reasonably tight roof may be expected. A roof is continually subjected to expansion stresses, as well as to atmospheric pressures, expecially if gases are removed for condensation purposes, and there is undoubtedly enough movement and distortion in the plates to make questionable the value of any great time spent on caulking. Red lead, or lac types of cement are sometimes used between sheets before riveting, but it is again doubtful whether such practice has any real advantage over a good workmanlike job of riveting with extra care at laps.

It will be noted in specifications for two 55,000-barrel storage tanks,[1] that five rings were specified instead of the usual six for tanks of the same height. Certain companies, notably the Shell Company of California, have constructed 30-foot tanks with only four rings, thus eliminating two horizontal and four vertical seams and thereby cutting down caulking over 15 per cent. On account of the extra weight of plate involved in such construction, it would appear that as a commercial competitive proposition such fabrication would only be feasible in periods of low material and high labor cost.

Too little attention is often given by tank builders to flanges, swing pipes; design of windlass boxes, etc. Fig. 27 shows excellent, substantial tank fittings. A damaged thread or a sprung flange causes a pipe to enter with difficulty, if at all, and wastes hours in erection, hence the requirement in the specifications to

[1] See p. 65.

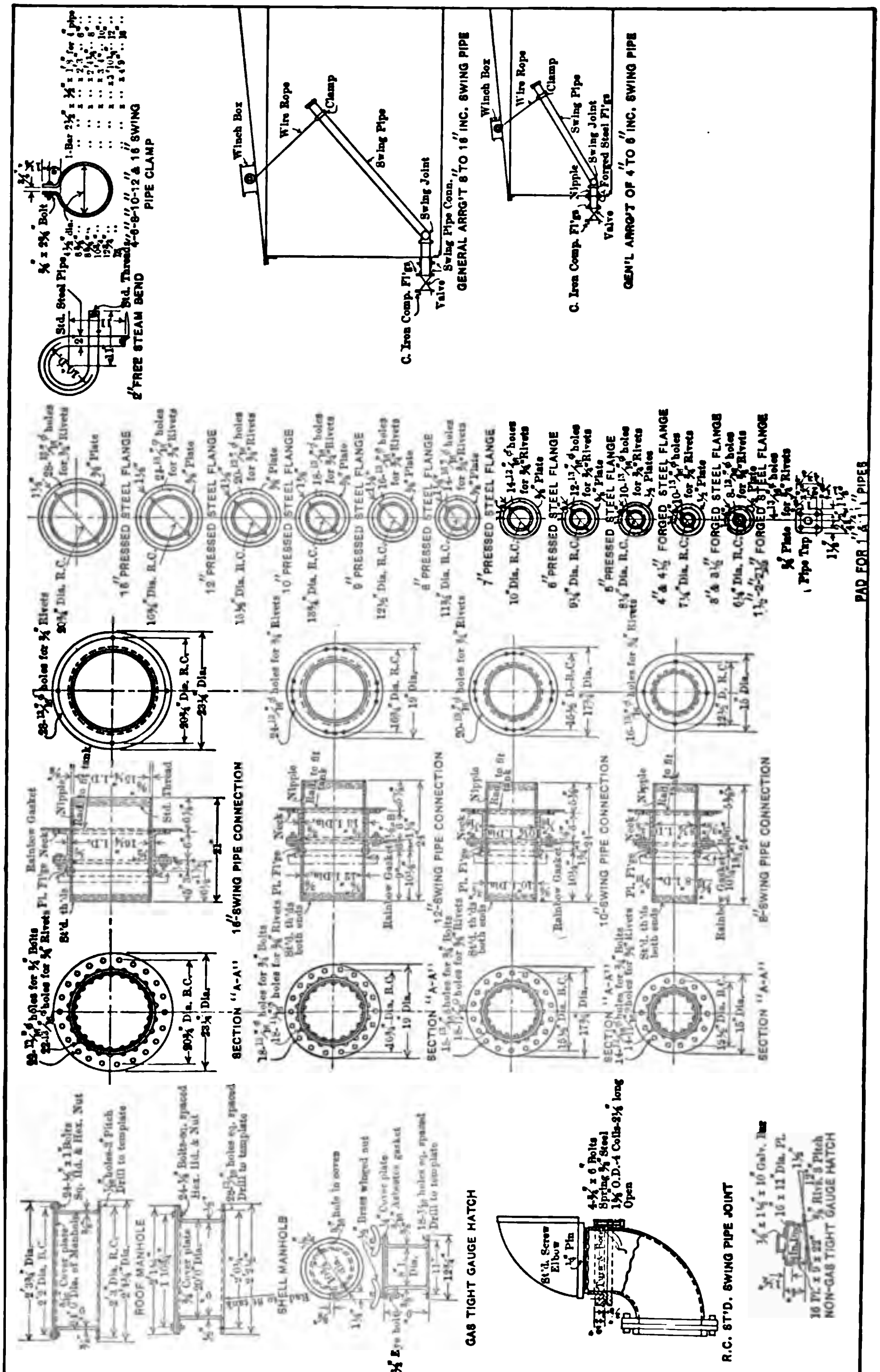


Fig. 27.—Standard tank-fitting details.

insert plugs before application. Windlasses should be designed with smooth-fitting gears and brass sleeve bearing, and should require only one man to raise a swing under ordinary service conditions. Moreover tank tops as well as manplates and explosion hatches should be gas-tight. Steel stairways should always be supplied when tanks are 25 feet or more in height, and are preferable with all tanks above 15 feet in height. Any gauger or sample boy dreads the greasy vertical iron ladder, and its employment above 20 feet is a menace to life and limb. Where it is installed, it should be carried past the top of the tank for 30 inches, the ends should be turned over and fastened to the roof sheets 2 feet back from the edge of the tank.

The standards thus far discussed and the critical comments offered concern average tank fabrication. The appended specifications, on the other hand, cover probably as heavy a tank of 55,000 barrels as has ever been built. Together with the contract requirements they will undoubtedly be of interest.

Specifications for 55,000-Barrel[1] *Tank with Steel Roof*[2] *and the Usual Form of Contract*

The (name of organization) in itself or by its duly authorized representative, shall be referred to in these specifications as the "Company."

The firm undertaking to furnish and erect the tank herein described, in itself or by its duly authorized representative, shall be referred to in these specifications as the "Contractor."

At all times during the progress of the fabrication of the tank material or the erection of the tank, the Contractor shall designate some person as his representative, to whom instructions may be given by a duly authorized representative of the Company.

1. **Location.**—The tank shall be erected upon a foundation prepared by the Company.

2. **Freight and hauling.**—The Contractor shall deliver all tank material, tools, and appliances f. o. b. cars nearest to the railroad station. The Company shall haul all tank material, tools, and appliances necessary for the construction of the tank from the railroad station, and shall deliver them within 100 feet of the tank site. On completion of the work they shall return all tools and appliances to the railroad station.

3. **Drawings.**—The following drawings form an integral part of and are to be used in conjunction with these specifications: Figs. 28–34.

4. **Dimensions.**—Diameter, 114 feet 6 inches, average inside measurement; height, 30 feet.

5. **Material.**—All material for the tank shall be of steel, complying with standard specifications for structural steel of the American Society for Testing Materials. The Contractor shall furnish a certificate from an approved firm of testing engineers to cover all materials used, but such a certificate shall not act to prevent the Company from exercising the right to reject undergaged plates or defective material wherever it may be found.

The tank shall be composed of six rings of equal height, as shown on Fig. 28. Plates shall be of uniform size with minimum dimensions, as hereinafter designated.

All plates shall be ordered to gage, permissible variations to be in accordance with the specifications for structural steel above referred to.

6. **Punching and riveting, etc.**—Plates and angles for the shell of the tank must be rolled to the proper curvature.

Plates and angles must be punched from the sides that are to be in contact. The punching must be so accurate that the holes will match within 10 per cent of their diameter when plates are assembled. Holes for hot rivets shall be punched not more than $\frac{1}{16}$ inch larger in diameter than the rivets that are to fill them.

[1] 42-gallon barrels. [2] Bureau of Mines, Bulletin 155, p. 5.

Riveting shall be done with pneumatic tools, an air pressure of approximately 90 pounds per square inch at the receiver being used. Rivets must conform with the specifications in diameter, length, pitch, and marginal distance. Should any burned, deformed, or loose rivets be found in the work, they are to be cut out and replaced.

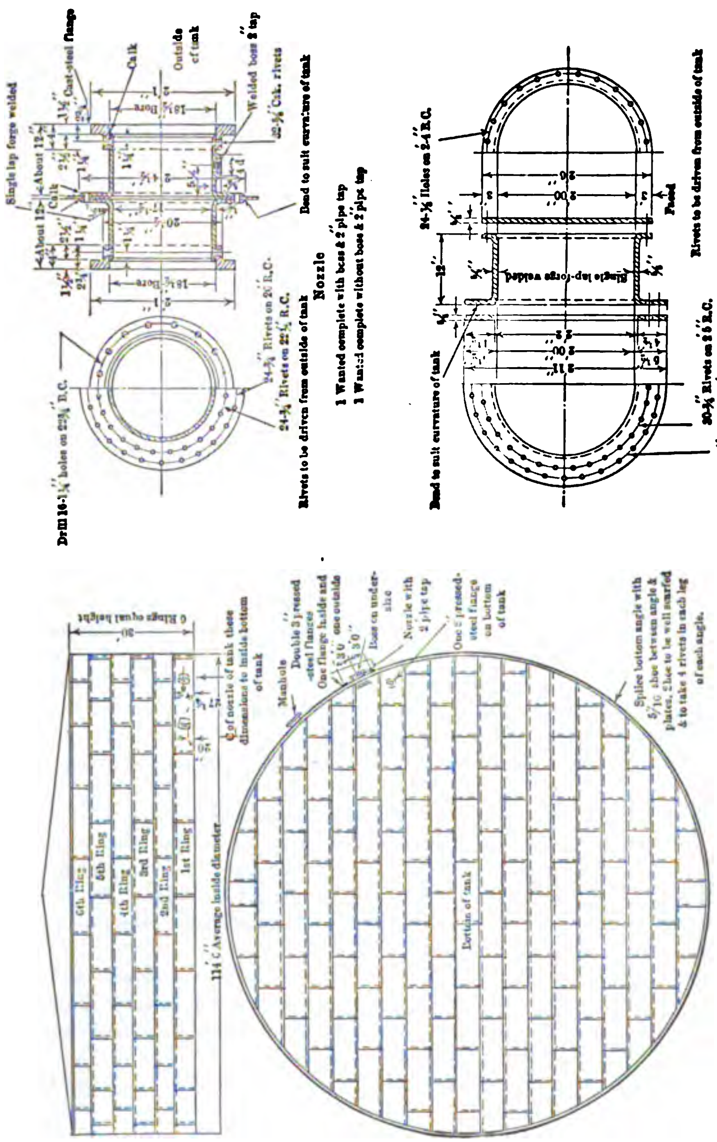


Fig. 28.—Details of a 55,000-barrel 6-ring steel tank.

No caulking of rivets will be allowed. Riveting of the bottom sheets shall be done from the inside. All other riveting, including riveting of the bottom to the bottom angle, and of the roof, shall be done from the outside. All rivets ¾ inch in diameter or larger shall be driven hot.

7. **Caulking.**—All edges to be caulked shall be beveled by planing. All seams must be thoroughly caulked with a round-nosed pneumatic caulking tool. The shell of the tank shall be formed by ascending inside courses caulked on the outside. Bottom plates shall be caulked on the inside except at the angle iron, where they are to be caulked on the outside. Both legs of the angle iron shall be caulked on the inside. Angle irons shall be butt-caulked at joints.

All roof plates shall be caulked from the outside of the tank. This shall also include caulking at the top angle iron.

All castings, nozzles, flanges, and manheads riveted to the tank must be caulked throughly inside and outside.

8. **Testing the bottom.**—Upon the completion of the bottom and the first ring of the shell, and before the bottom has been lowered to the ground, it shall be covered with water to a depth of not less than 5 inches. All leaks that develop shall be made tight, to the satisfaction of the Company or its duly authorized representative before any lowering is done. Necessary water for the testing shall be furnished by the Company for one test only. Should additional tests be made, the water shall be charged to the contractor at cost.

9. **Thickness of metal, spacing of rivets, etc.**—The thickness of metal, the spacing of rivets, and the like shall be as set forth in the following table:

Thickness of Metal, Spacing of Rivets, etc., Prescribed for the Tank Covered by these Specifications

Part	Thickness	Weight per square foot	Horizontal Riveting—All Single Rows		Vertical Riveting			
			Diameter of rivets	Pitch	Rows	Diameter of rivets	Pitch	Distance between rows, center to center
	Inches	Pounds	Inches	Inches		Inches	Inches	Inches
Bottom sketch plates	$\frac{5}{16}$	12.75	$\frac{1}{2}$	$1\frac{1}{2}$				
Bottom rectangular plates	$\frac{1}{4}$	10.20	$\frac{1}{2}$	$1\frac{1}{2}$				
First ring	$\frac{9}{16}$	22.95	1	$2\frac{1}{2}$	Triple	$\frac{3}{4}$	3	2
Second ring	$\frac{1}{2}$	20.40	$\frac{7}{8}$	$2\frac{1}{2}$	Triple	$\frac{3}{4}$	3	2
Third ring	$\frac{13}{32}$	16.58	$\frac{3}{4}$	$2\frac{1}{2}$	Double	$\frac{3}{4}$	$2\frac{1}{2}$	2
Fourth ring	$\frac{5}{16}$	12.75	$\frac{3}{4}$	$2\frac{1}{2}$	Double	$\frac{5}{8}$	$2\frac{1}{4}$	$1\frac{3}{4}$
Fifth ring	$\frac{1}{4}$	10.20	$\frac{5}{8}$	2	Double	$\frac{5}{8}$	$2\frac{1}{4}$	$1\frac{3}{4}$
Sixth ring	$\frac{1}{4}$	10.20	$\frac{5}{8}$	2	Double	$\frac{5}{8}$	$2\frac{1}{4}$	$1\frac{3}{4}$
Roof plates	$\frac{3}{16}$	7.65	$\frac{3}{8}$	$1\frac{1}{4}$				

10. **Size of plates and angles.**—Plates for shell shall be 60 by 180 inches center to center of rivet laps (24 plates per ring). Bottom and top rectangular plates shall

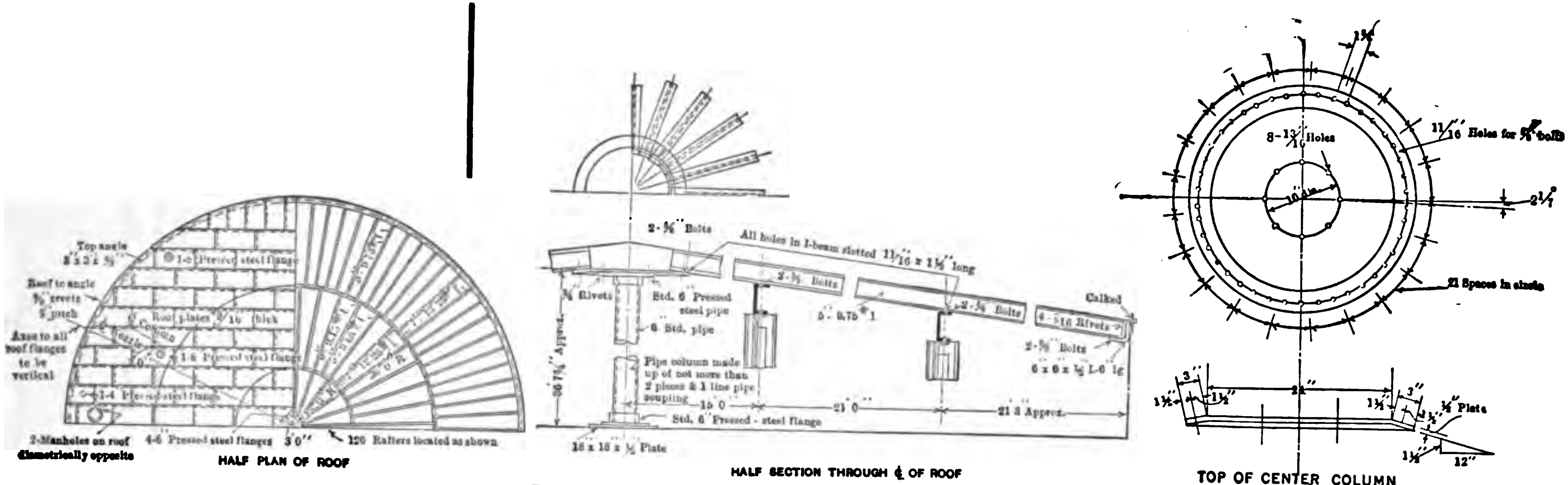


Fig. 29.—Steel roof and supports for a 55,000-barrel tank.

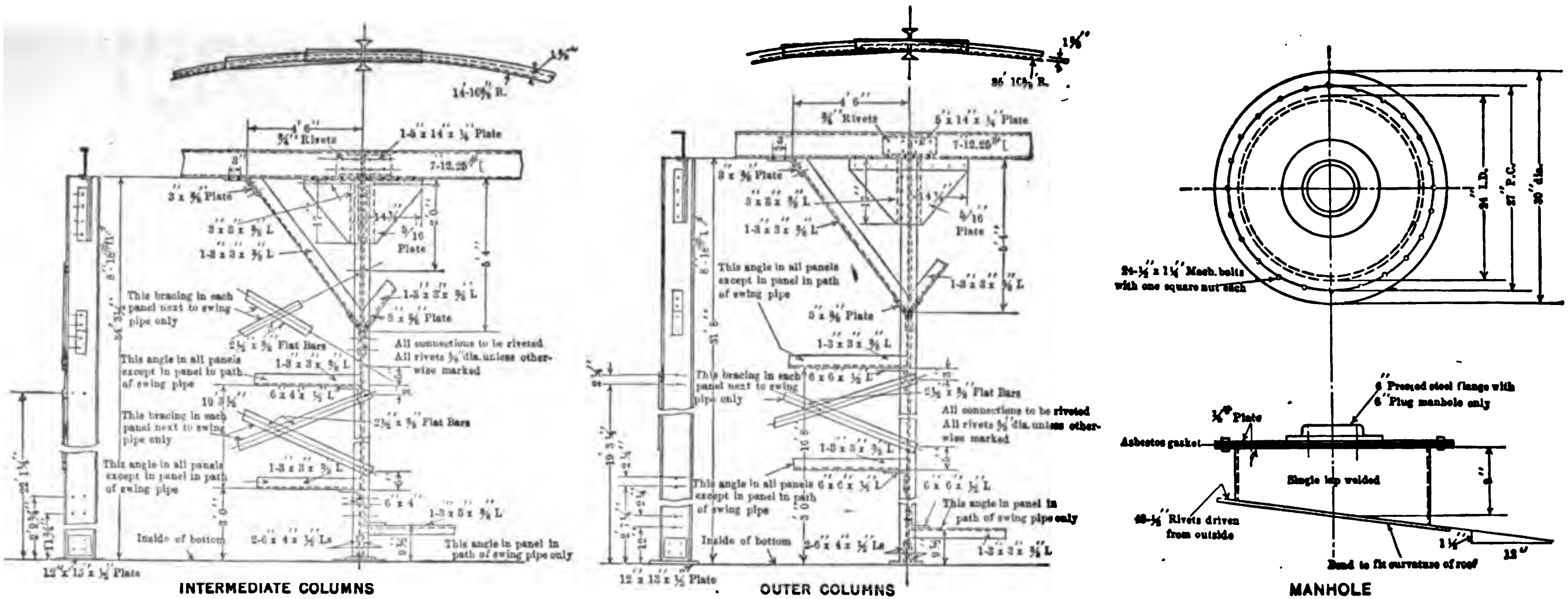
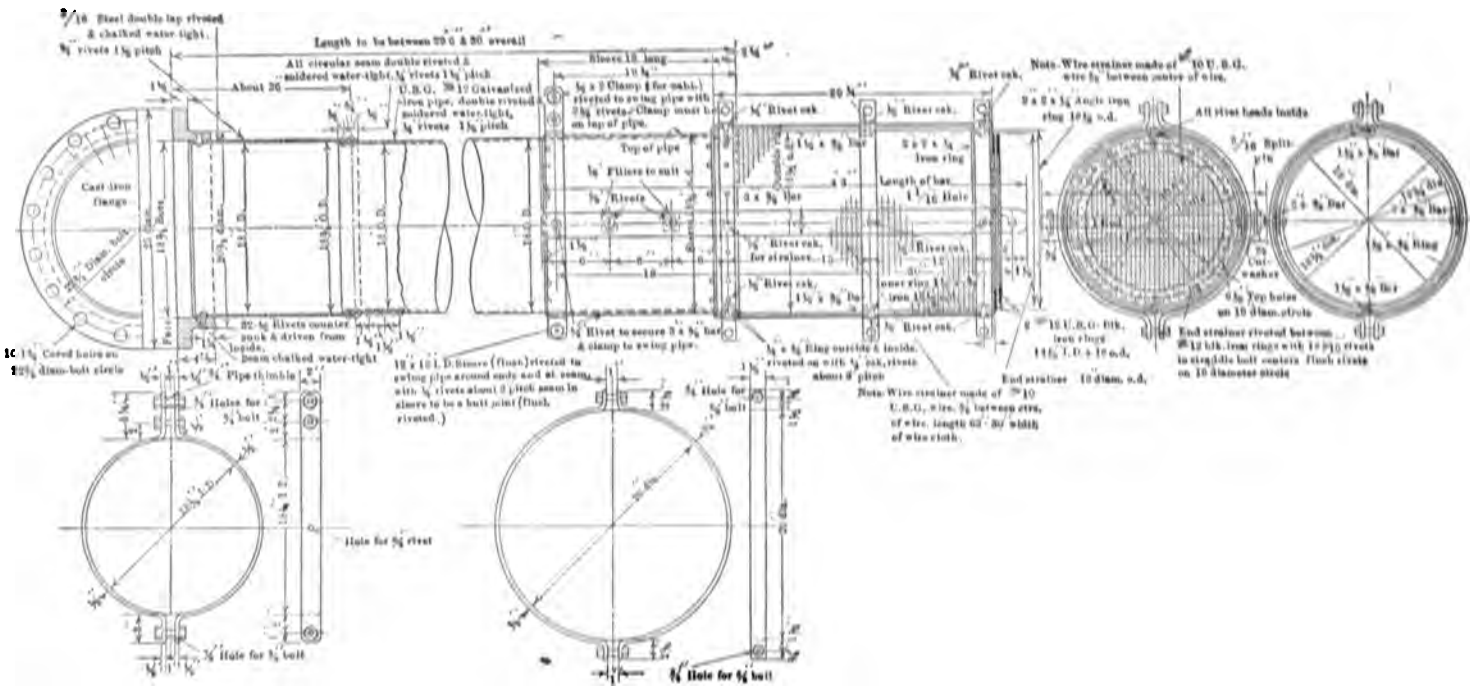


Fig. 2[illegible].—Steel roof and supports for a 55,000-barrel tank.



DETAIL OF CLAMP FOR CABLE
1 Required

DETAIL OF CLAMP FOR STRAINER
3 Required

Fig. 80.—18-inch swing pipe.

be 60 by 180 inches center to center of rivet laps. Bottom angle irons connecting the bottom and the shell shall be 4 by 4 inches by ⅜ inch. Top angle iron connecting the roof with the shell shall be 3 by 3 inches by ⅜ inch.

11. **Angle shoes.**—Shoes uniting the ends of angles shall be made of ⅜-inch 16-pound steel, and shall be not less than 12 inches in length with the ends drawn to a thin edge. Shoes must be set between steel angles, shell and bottom of tank, and must be of sufficient width to be properly caulked outside the line of the steel angles.

12. **Shell.**—The shell shall be composed of six courses, as shown in Fig. 28, each course to be of true circle and to be free from flaws and buckles. The first two courses, counting from the bottom upward, are to have the vertical seams triple riveted. The third, fourth, and fifth courses are to have the vertical seams double riveted. All horizontal seams are to be single riveted.

13. **Roof.**—The roof shall be composed of $\frac{3}{16}$-inch steel plates weighing 7.65 pounds per square foot, and shall rest on steel roof supports as shown in Fig. 29. The roof, however, shall not be riveted to the roof supports at any point. When complete the roof must be "gas tight," and shall show no leaks when tested with an air pressure equal to the weight of the roof.

14. **Roof supports.**—Roof supports shall be constructed of steel shapes as shown on Fig. 29. Size and fabrication shall conform to those shown, and workmanship shall be approved by the Company.

15. **Manholes.**—Two manholes shall be placed in the first course of the tank, as designated by the Company in the field. Each manhole shall be 20 inches deep, and shall be made of steel with welded seam, weighing not less than 21 pounds per square foot. The neck of the flange must be covered to suit the radius of the tank shell. The manhole shall be fitted with a steel cover plate ⅜-inch thick, faced and punched to suit the holes in the flange, and bolted to flange with 24 ¾-inch square-head bolts and hexagon nuts. The manhole shall be riveted to the tank shell with ¾-inch rivets, as shown on Fig. 28.

16. **Pipe flanges, nozzles, etc.**—The tank shall be furnished with the following pressed-steel flanges, secured to the shell with ¾-inch diameter rivets. The position in the field shall be designated by the Company. One pair of flanges shall be threaded for 8-inch pipe for drawing off water. One pair of flanges shall be threaded for 8-inch pipe for oil-inlet pipe. The bottom of the tank shall be fitted with one single flange threaded for 8-inch pipe, secured to the bottom of the tank with ½-inch rivets. Roof of tank shall be fitted with two 8-inch and one 4-inch pressed-steel flanges. They shall also have manholes and gage hatch, as shown in detail on Fig. 29.

The tank shall be fitted with one combined swing pipe and suction nozzle, as shown in detail on Fig. 28, page 102. The nozzle shall be made of single-lap, forge-welded steel ½ inch thick, and shall be secured to the shell of the tank, with a double row of ¾-inch rivets, as shown in the drawing. The swing pipe and suction end of the nozzle shall be fitted with a cast-steel flange, as shown.

17. **Swing pipe.**—The contractor shall supply and install a swing pipe as shown in detail on Fig. 30. The swing pipe shall be delivered on the job so that it may be placed, but not installed, inside of the tank shell as soon as the bottom is tested and lowered. The contractor shall not be permitted to lift the swing pipe over the shell of the tank after more than the first ring of the tank is in position.

18. **Double-swivel joint for swing pipe.**—The contractor shall supply and install to the satisfaction of the Company a double-swivel elbow joint for connecting the swing pipe to the swing-pipe nozzle. Details for this swivel joint are shown on Fig. 31. The construction of the joint must follow details closely as per drawing.

19. **Stairway.**—The contractor shall furnish and install a stairway anchored to the shell of the tank and running from the ground to the top of the tank, as shown

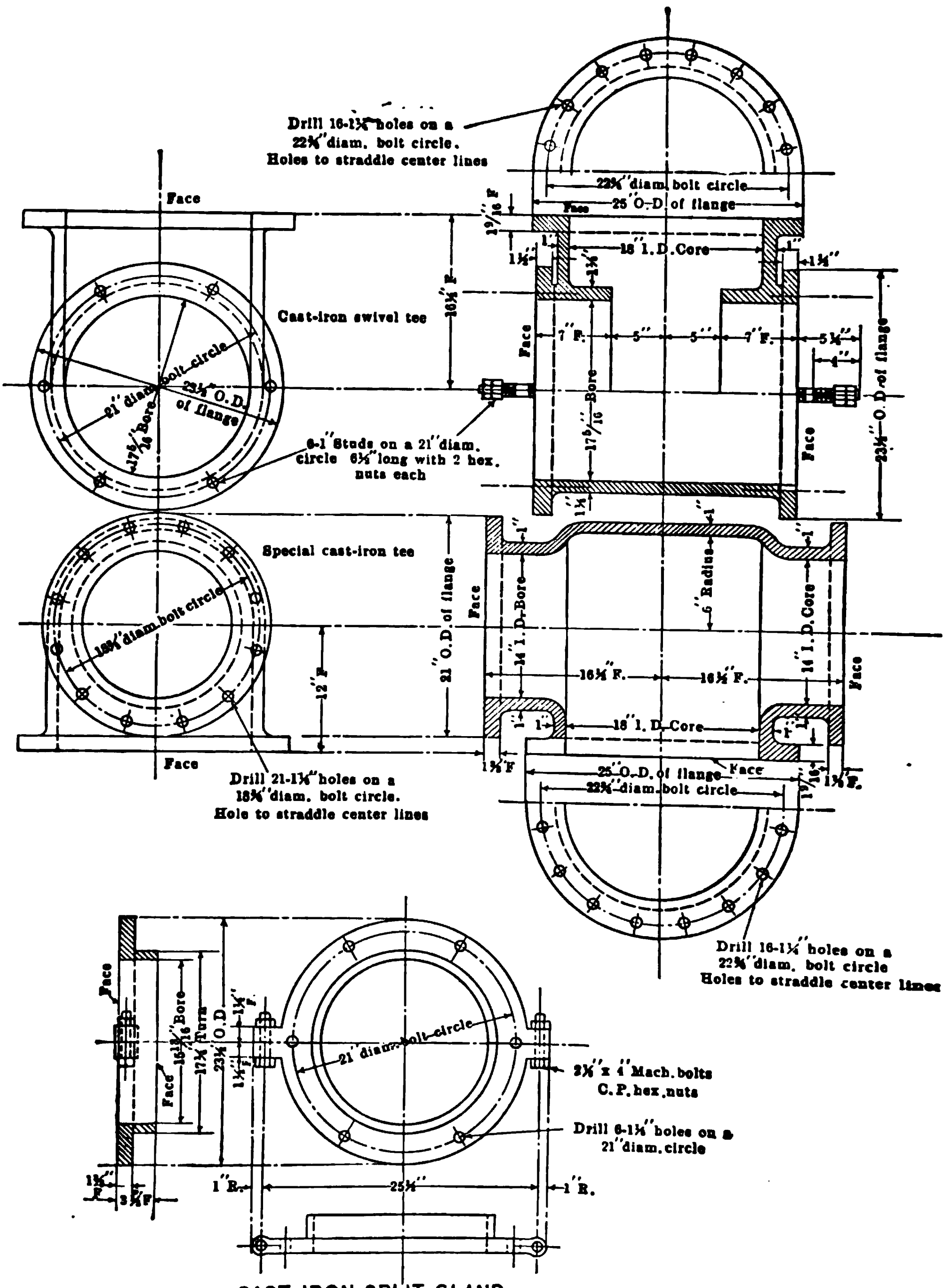
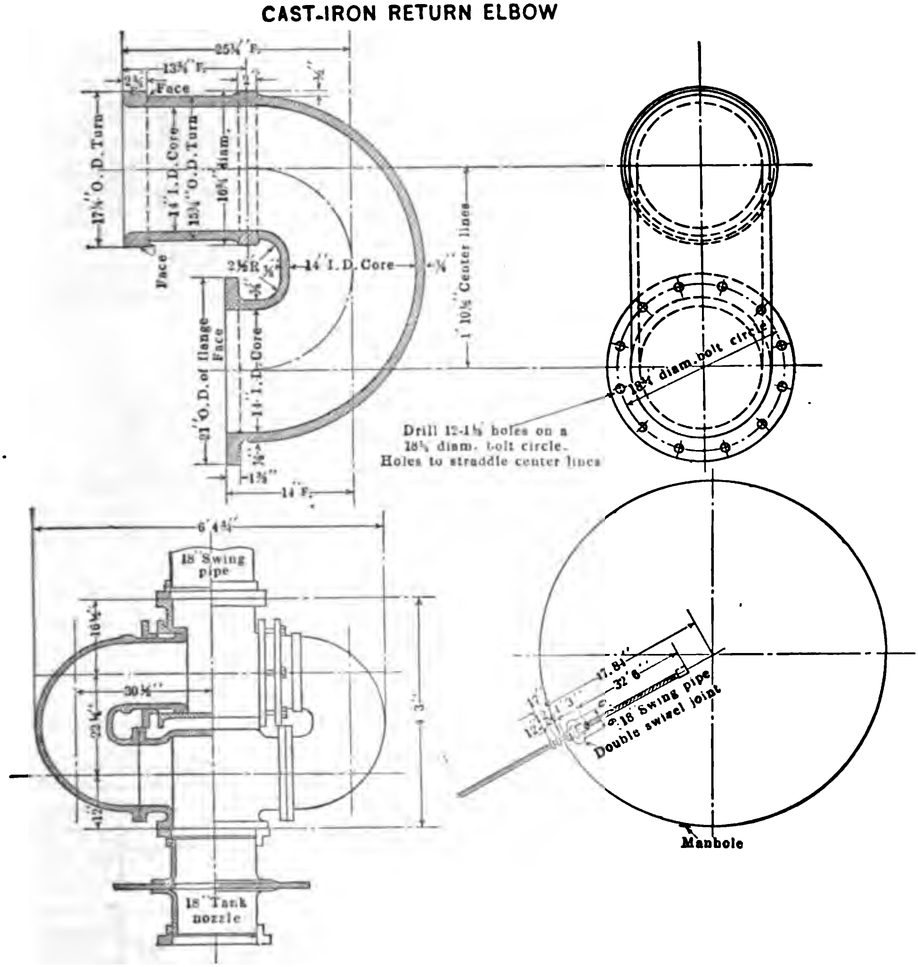


FIG. 31.—Double swivel for 18-inch swing pipe.

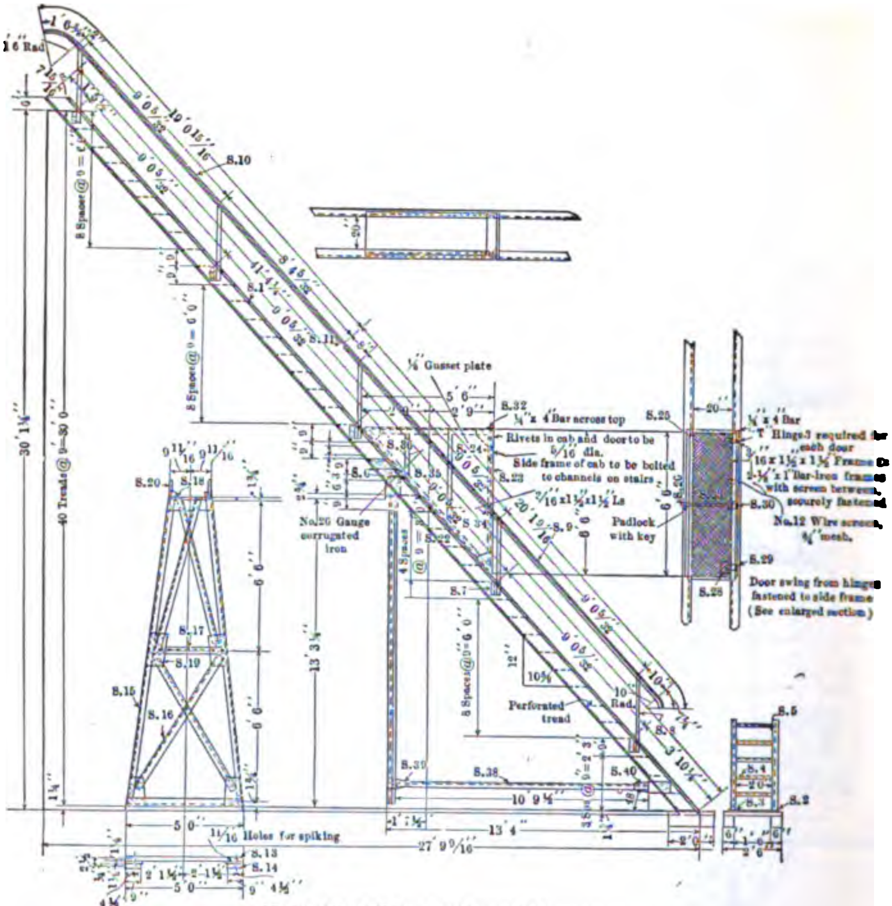
CAST-IRON RETURN ELBOW



GENERAL ARRANGEMENT

JOINT FOR 18-INCH SWING PIPE

Fig. 31.—Double swivel for 18-inch swing pipe.



STANDARD STEEL STAIRS FOR 30 FOOT TANK

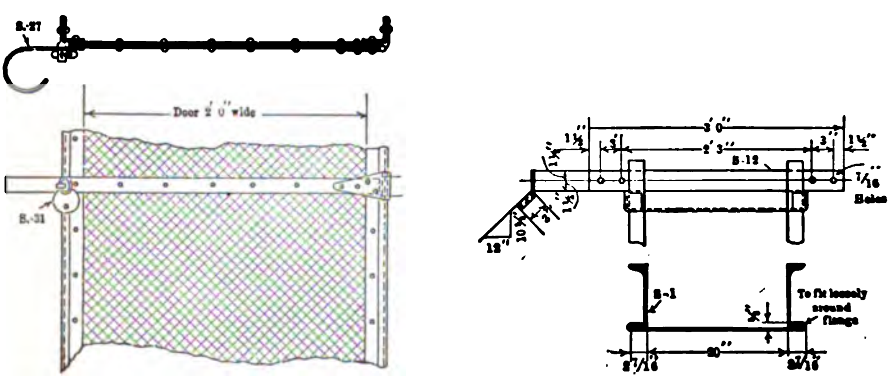


FIG. 32.—Gate for standard steel stairs for 30-foot tank.

on Fig. 32. This stairway shall be equipped with a door covered with No. 12 wire screen, $\frac{3}{4}$-inch mesh, as shown on Fig. 32.

20. **Explosion hatches.**—The tank shall be equipped with eight explosion hatches to be located on the roof of the tank in the field as designated by the Company. Details of explosion hatches are shown on Fig. 33. These explosion hatches are to be furnished by the Contractor and must conform closely to the drawing. Brass rods must be true and smoothly turned, and must be accurately fitted in babbitted bearings, as shown, in order that the aluminum cover of the hatch will rise without binding.

21. **Cable guides and stuffing box.**—The tank shall be provided with cable guides and stuffing box for cable, as shown in detail on Fig. 34. One hundred feet of $\frac{1}{2}$-inch diameter 6-strand 19-wire plow-steel galvanized-wire cable shall be furnished by the Contractor. Sheave wheels for the cable must be accurately centered and supports securely riveted to the tank shell and caulked inside and outside of the tank.

22. **Swing-pipe winch.**—A swing-pipe winch shall be furnished by the Contractor as per detail shown in Fig. 34, and shall be placed in position by Contractor where designated by the Company.

23. **Painting.**—The outside of the tank, including the top, shall be painted with one coat of asphaltic, graphite, or other paint approved by the Company, to be spread on with a brush and to thoroughly cover the metal. The bottom of the tank shall be painted with three coats of the same paint, at least six hours being allowed for each coat to dry.

24. **Inspection.**—All material and workmanship shall be subject at all times to the inspection of the Company, and any defective material, whether discovered before or after it has been used in the work, shall be replaced in the construction by the Contractor at his own expense. The Contractor shall also furnish transportation from the railroad to the tank site for such new material.

25. **Final test.**—Upon the completion of the tank, and before it is inspected, it may be filled with oil or water at the option and expense of the Company and any leaks that develop shall be made tight to the satisfaction of the Company by the Contractor at his own expense.

26. **Boarding of work crew.**—The Contractor shall provide board, lodging, and transportation for his men at all times. Commissary water shall be furnished by the Company. Purification of the water, where necessary, shall be done by the Contractor. No intoxicating liquors shall be permitted on the premises.

27. **Workmanship.**—The work throughout shall be done in first-class workmanlike manner, and only men competent in their line shall be employed about the work. Upon demand of the Company, any workman who in the judgment of the Company is found to be incompetent, careless, or intemperate shall be dismissed.

28. **Extra work.**—These plans and specifications are intended to describe a complete oil-tight and gas-tight tank. Any work and material necessary to produce such a tank, although not mentioned in the specifications or shown on the plans, shall be supplied by the Contractor without extra cost to the Company. The Company shall not pay for extra work unless it has been executed on a written order by the Company, or its duly authorized representative.

29. **Rubbish.**—On completion of the work all useless material used in the construction shall be cleared away from inside and outside of the tank, and shall be removed to such a point upon the premises as may be designated by the Company.

30. **Camp sanitation.**—The Contractor shall at all times maintain his boarding house, sleeping quarters, and all other appurtenant facilities in a sanitary condition to the satisfaction of the Company.

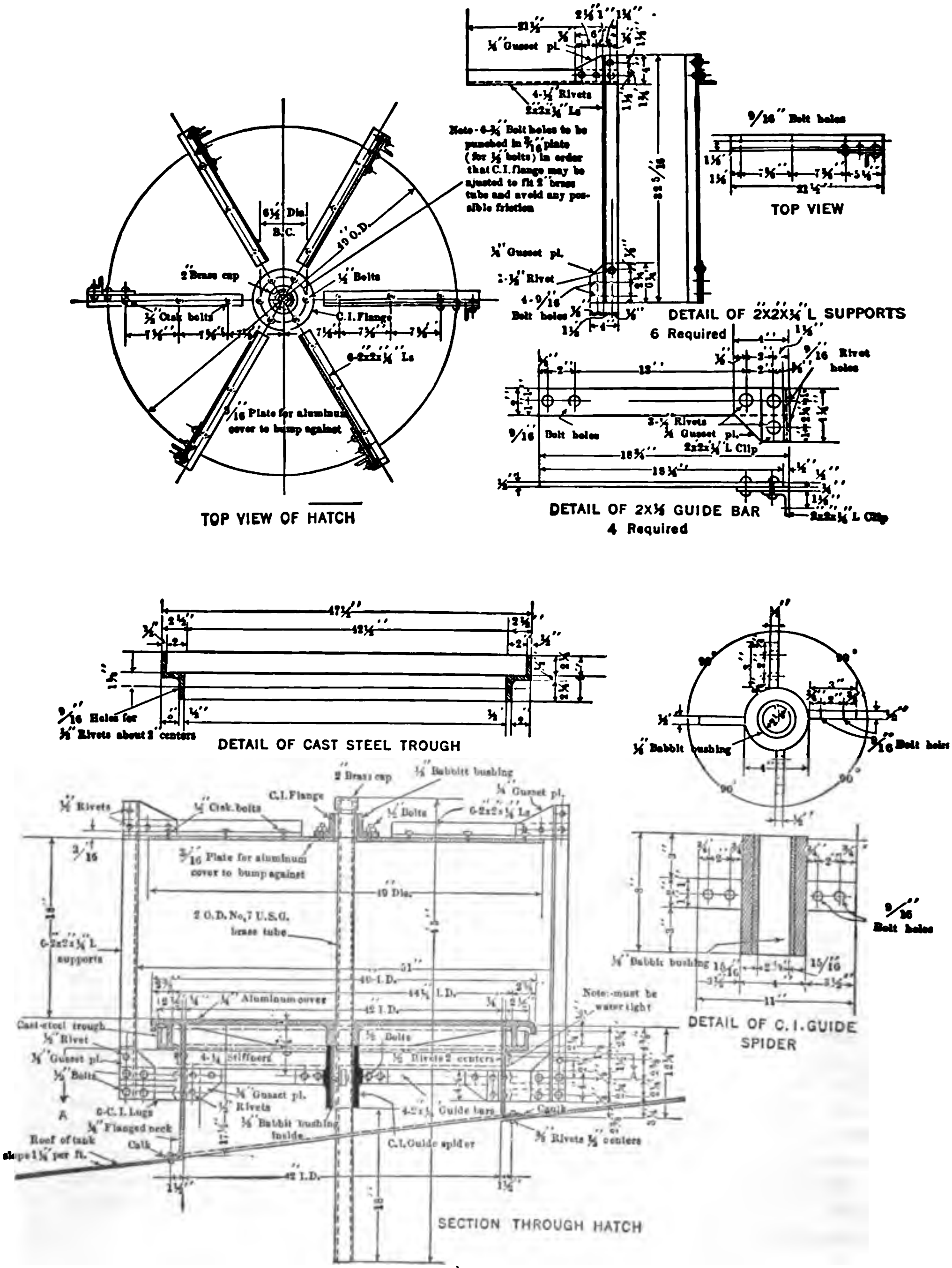


FIG. 33.—Details of explosion hatch for tank roof.

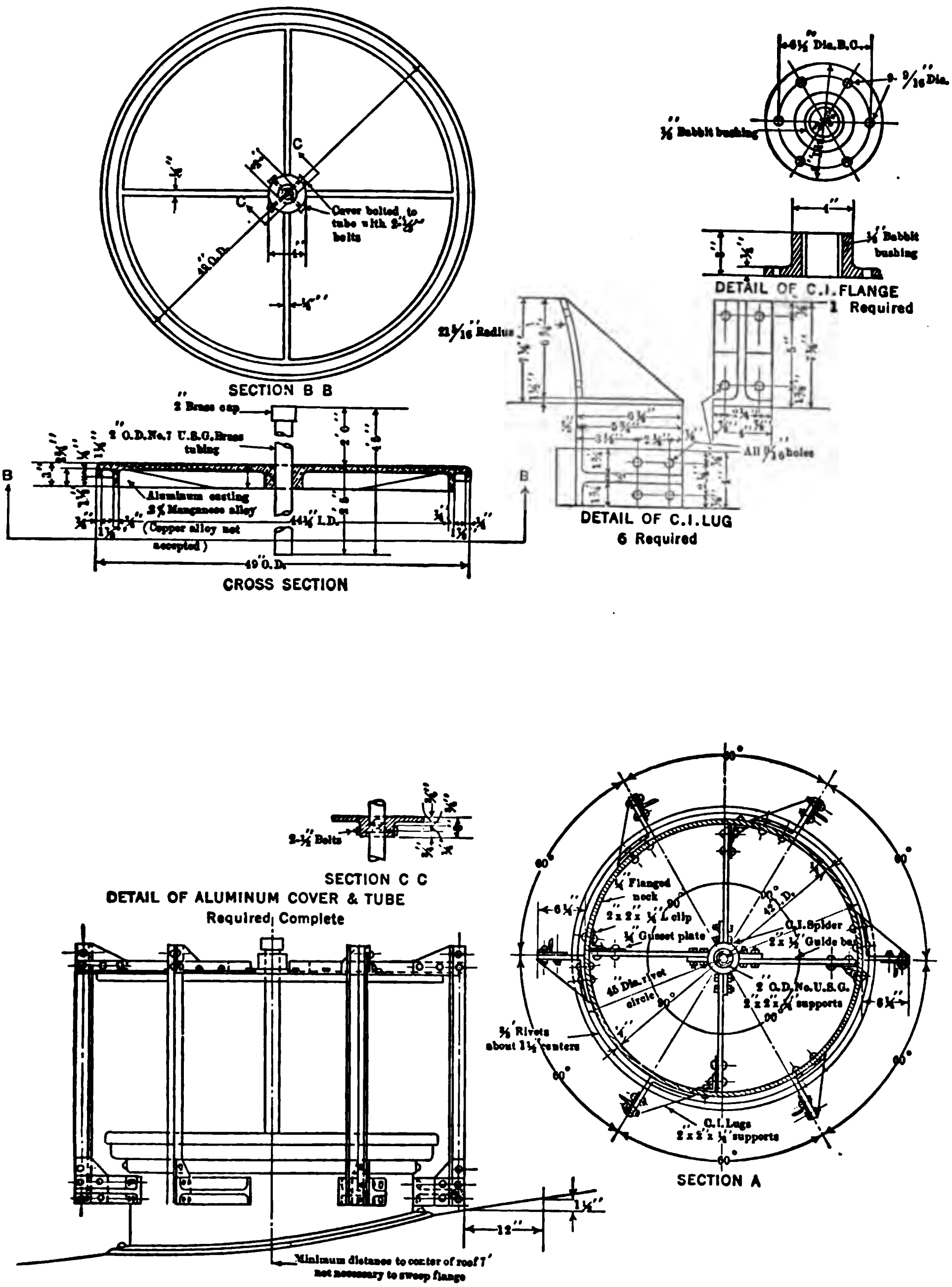
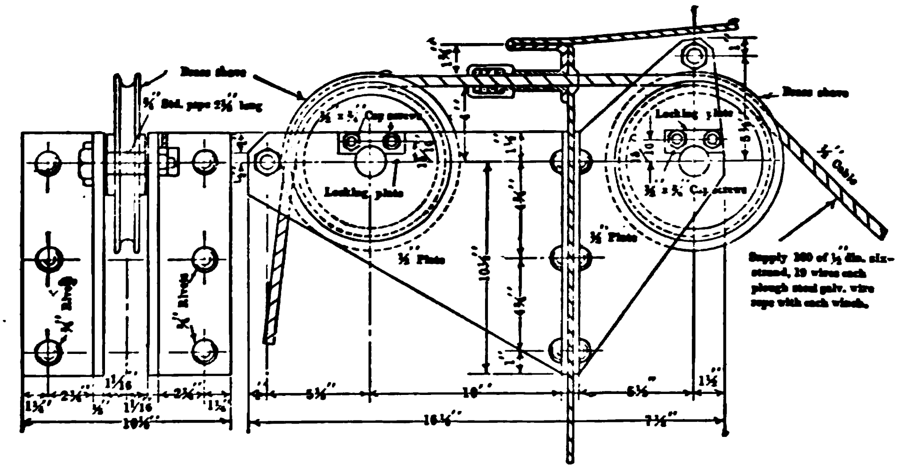
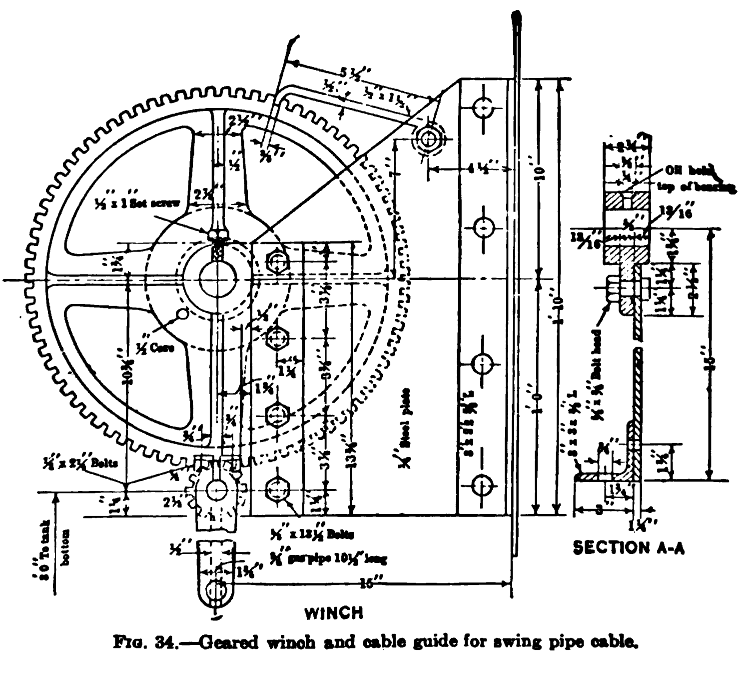


Fig. 33.—Details of explosion hatch for tank roof.



CABLE GUIDE



WINCH

Fig. 34.—Geared winch and cable guide for swing pipe cable.

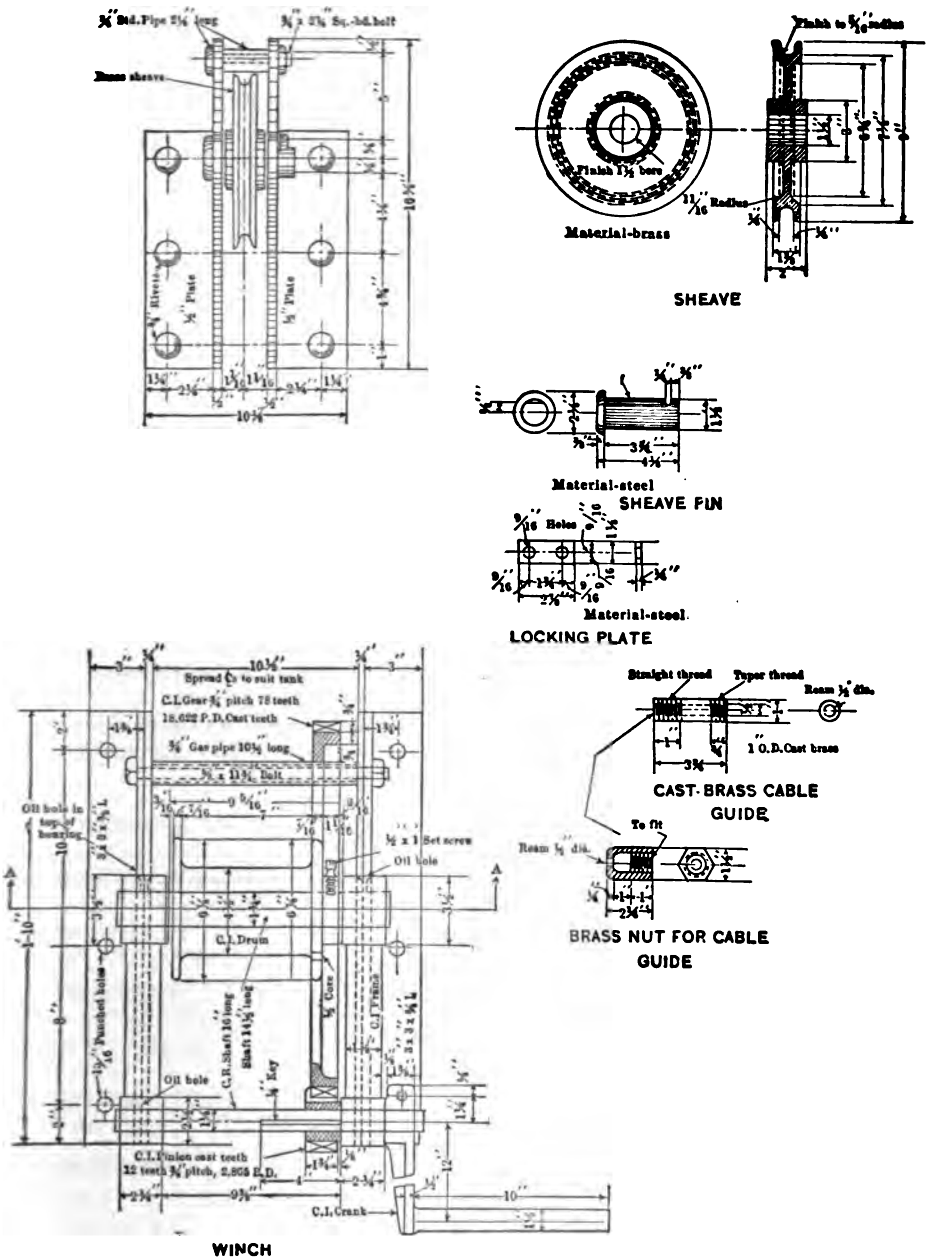


Fig. 34.—Geared winch and cable guide for swing pipe cable.

TANK STEEL SPECIFICATIONS—STANDARD SPECIFICATIONS FOR STRUCTURAL STEEL FOR BUILDINGS[1]

I. Manufacture

1. **Process.**—(*a*) Structural steel, except as noted in paragraph *b*, may be made by the Bessemer or the open-hearth process.

(*b*) Rivet steel, and steel for plates or angles over ¾-inch in thickness, which are to be punched, shall be made by the open-hearth process.

II. Chemical Properties and Tests

2. **Chemical composition.**—The steel shall conform to the following requirements as to chemical composition.

		Structural steel	Rivet steel
Phosphorus	Bessemer	Not over 0.10 per cent	....
	Open-hearth	Not over 0.06 per cent	Not over 0.06 per cent
Sulphur		....	Not over 0.045 per cent

3. **Ladle analyses.**—An analysis of each melt of steel shall be made by the manufacturer to determine the percentages of carbon, manganese, phosphorus, and sulphur. This analysis shall be made from a test ingot taken during the pouring of the melt. The chemical composition thus determined shall be reported to the purchaser or his representative, and shall conform to the requirements specified in section 2.

4. **Check analyses.**—Analyses may be made by the purchaser from finished material representing each melt. The phosphorus and sulphur content thus determined shall not exceed that specified in section 2 by more than 25 per cent.

III. Physical Properties and Tests

5. **Tension tests.**—(*a*) The material shall conform to the following requirements as to tensile properties:

Properties considered	Structural steel	Rivet steel
Tensile strength, pounds per square inch	55,000 to 65,000	46,000 to 56,000
Yield point, minimum, pounds per square inch	0.5 tensile strength	0.6 tensile strength
Elongation in 8 inches, minimum, per cent.	$\frac{1,400,000\ *}{\text{Tensile strength}}$	$\frac{1,400,000}{\text{Tensile strength}}$
Elongation in 2 inches, minimum, per cent	22	....

* See Section 6.

[1] American Society for Testing Materials. Philadelphia, Pa., U. S. A. Affiliated with the International Association for Testing Materials.
Serial designation: A 9-16. Adopted 1901; revised 1909, 1913, 1914, 1916.

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

6. **Modifications in elongation.**—(*a*) For structural steel over ¾ inch in thickness, a deduction of 1 from the percentage of elongation in 8 inches specified in section 5, *a*, shall be made for each increase of ⅛ inch in thickness above ¾ inch, to a minimum of 18 per cent.

(*b*) For structural steel under $\frac{5}{16}$ inch in thickness, a deduction of 2.5 from the percentage of elongation in 8 inches specified in section 5, *a*, shall be made for each decrease of $\frac{1}{16}$ inch in thickness below $\frac{5}{16}$ inch.

7. **Bend tests.**—(*a*) The test specimen for plates, shapes, and bars, except as specified in paragraphs *b* and *c*, shall bend cold through 180° without cracking on the outside of the bent portion, as follows: For material ¾ inch or under in thickness, flat on itself; for material over ¾ inch to and including 1¼ inches in thickness, around a pin the diameter of which is equal to the thickness of the specimen; and for material

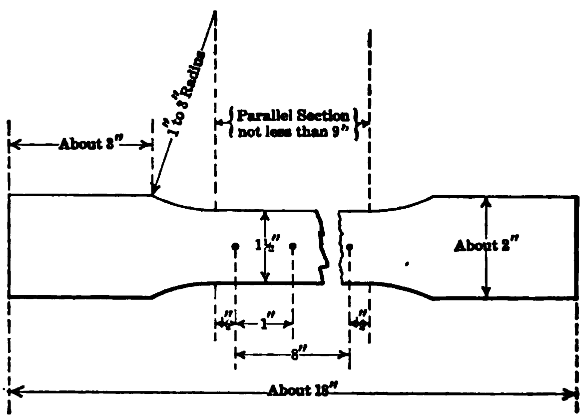


Fig. 35.—Specimen for tension and bending test.

over 1¼ inches in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen.

(*b*) The test specimen for pins, rollers, and other bars, when prepared as specified in section 8, *e*, shall bend cold through 180° around a 1-inch pin without cracking on the outside of the bent portion.

(*c*) The test specimen for rivet steel shall bend cold through 180° flat on itself without cracking on the outside of the bent portion.

8. **Test specimens.**—(*a*) Specimens for tension and bending tests shall be taken from rolled steel in the condition in which it comes from the rolls, except as specified in paragraph *b*.

(*b*) Specimens for tension and bending tests of pins and rollers shall be taken from the finished bars, after annealing when annealing is specified.

(*c*) Specimens for tension and bending tests of plates, shapes, and bars, except as specified in paragraphs *e* and *f*, shall be of the full thickness of material as rolled, and may be machined to the form and dimensions shown in Fig. 35, or with both edges parallel.

(*d*) Specimens for tension ana bending tests of plates over 1½-inches in thickness may be machined to a thickness or diameter of at least ¾ inch for a length of at least 9 inches.

(*e*) Specimens for tension tests of pins, rollers, and bars more than 1½ inches in thickness or diameter may conform to the dimensions shown in Fig. 36. In this case, the ends shall be of a form to fit the holders of the testing machine in such a way that the load shall be axial. Bend test specimens may be 1 by ½ inch in section. The axis of the specimen shall be located at any point midway between the center and surface and shall be parallel to the axis of the bar.

(*f*) Specimens for tension and bending tests of rivet steel shall be of the full-size section of bars as rolled.

9. **Number of tests.**—(*a*) One tension and one bending test shall be made of material from each melt, except that if material from one melt differs ⅜ inch or more in thickness, one tension and one bending test shall be made from both the thickest and the thinnest material rolled.

(*b*) If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted.

(*c*) If the percentage of elongation of any tension-test specimen is less than that

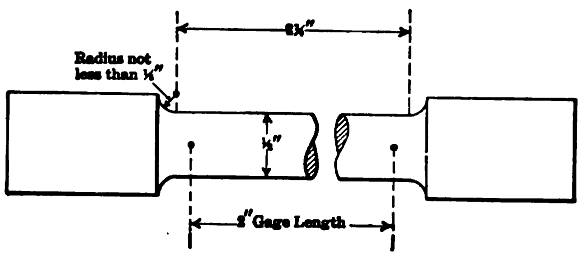


Fig. 36.—Specimen for tension test.

specified in section 5, *a*, and any part of the fraction is more than ¾ inch from the center of the gage length of a 2-inch specimen or is outside the middle third of the gage length of an 8-inch specimen, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

IV. Permissible Variations in Weight and Thickness

10. **Permissible variations.**—The cross-section or weight of each piece of steel shall not vary more than 2.5 per cent from that specified, except in the case of sheared plates, which shall be covered by the following permissible variations. One cubic inch of rolled steel is assumed to weigh 0.2833 pound.

(*a*) When ordered to weigh per square foot, the weight of each lot [1] in each shipment shall not vary from the weight ordered more than the amount given in Table 1.

(*b*) When ordered to thickness, the thickness of each plate shall not vary more than 0.01 inch under that ordered.

The overweight of each lot [2] in each shipment shall not exceed the amount given in Table 2.

[1] The term "lot" applied to Table 1 means all of the plates of each group width and group weight.

[2] The term "lot" applied to Table 2 means all of the plates of each group width and group thickness.

TABLE 1.

Permissible Variations of Plates Ordered to Weight

Ordered weight pounds per square feet	PERMISSIBLE VARIATIONS IN WEIGHT OF PLATE FOR WIDTH GIVEN, EXPRESSED IN PERCENTAGE OF ORDERED WEIGHT																	
	Under 48 inches		48 inches, inclusive, to 60 inches, exclusive		60 inches, inclusive, to 72 inches, exclusive		72 inches, inclusive, to 84 inches, exclusive		84 inches, inclusive, to 96 inches, exclusive		96 inches, inclusive, to 108 inches, exclusive		108 inches, inclusive, to 120 inches, exclusive		120 inches, inclusive, to 132 inches, exclusive		132 inches and over	
	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under
Under 5.............	5	3	5.5	3	6	3	7	3										
5 incl. to 7.5 excl.	4.5	3	5	3	5.5	3	6	3										
7.5 incl. to 10 excl.	4	3	4.5	3	5	3	5.5	3	6	3	7	3	8	3				
10 incl. to 12.5 excl.	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3	8	3	9	3
12.5 incl. to 15 excl.	3	2.5	3.5	2.5	4	3	4.5	3	5	3.	5.5	3	6	3	7	3	8	3
15 incl. to 17.5 excl.	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3
17.5 incl. to 20 excl.	2.5	2	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3
20 incl. to 25 excl.	2	2	2.5	2	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3
25 incl. to 30 excl.	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3	4.5	3	5	3
30 incl. to 40 excl.	2	2	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3	4.5	3
40 and over..........	2	2	2	2	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3

TABLE 2.

Permissiote Overweights of Plates Ordered to Thickness

Ordered thickness inches	Permissible Excess in Average Weights per Square Foot of Plates, for Widths Given, Expressed in Percentages of Nominal Weights								
	Under 48 inches exclusive	48 to 60 inches, exclusive	60 to 72 inches, exclusive	72 to 84 inches, exclusive	84 to 96 inches, exclusive	96 to 108 inches, exclusive	108 to 120 inches, excluvsie	120 to 132 inches, exclusive	132 inches or over
Under 1/8	9	10	12	14					
1/8 to 3/16, exclusive	8	9	10	12					
3/16 to 1/4, exclusive	7	8	9	10	12				
1/4 to 5/16, exclusive	6	7	8	9	10	12	14	16	19
5/16 to 3/8, exclusive	5	6	7	8	9	10	12	14	17
3/8 to 7/16, exclusive	4.5	5	6	7	8	9	10	12	15
7/16 to 1/2, exclusive	4	4.5	5	6	7	8	9	10	13
1/2 to 5/8, exclusive	3.5	4	4.5	5	6	7	8	9	11
5/8 to 3/4, exclusive	3	3.5	4	4.5	5	6	7	8	9
3/4 to 1, exclusive	2.5	3	3.5	4	4.5	5	6	7	8
1 or over	2.5	2.5	3	3.5	4	4.5	5	6	7

V. FINISH

11. **Finish.**—The finished material shall be free from injurious defects and shall have a workmanlike finish.

VI. MARKING

12. **Marking.**—The name or brand of the manufacturer and the melt number shall be legibly stamped or rolled on all finished material, except that rivet and lattice bars and other small sections shall, when loaded for shipment, be properly separated and marked for identification. The identification marks shall be legibly stamped on the end of each pin and roller. The melt number shall be legibly marked, by stamping if practicable, on each test specimen.

VII. INSPECTION AND REJECTION

13. **Inspection.**—The inspector representing the purchaser shall have free entry, at all times while work on the purchaser's contract is being performed, to all parts of the works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests, except check analyses, and inspection shall be made at the place of manufacture prior to shipment unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

14. **Rejection.**—(*a*) Unless otherwise specified, any rejection based on tests made in accordance with Section 4 shall be reported within five working days from the receipt of samples.

(*b*) Material that shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer will be notified.

15. **Rehearing.**—Samples tested in accordance with section 4, which represent rejected material, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

As frequent reference to manufacturers' standard specifications as adopted by the Association of American Steel Manufacturers has been made in the preceding chapter, their specifications are also appended. These, it will be noted, demand a slight improvement in chemical composition over A. S. T. M. standards, with the physical characteristics substantially the same. The permissible variations in plate being identical. Such tables are omitted.

MANUFACTURERS' STANDARD SPECIFICATIONS, REVISED APRIL 21, 1919

STRUCTURAL STEEL

1. **Grades.**—These specifications cover three classes of structural steel, namely:

Class A steel, to be used for railway bridges and ships.

Class B steel,[1] to be used for buildings, highway bridges, train sheds and similar structures.

Class C steel, to be used for structural rivets.

I. PROCESS OF MANUFACTURE

2. Steel for Classes A and C shall be made by the open-hearth process. Steel for Class B may be made either by the open-hearth or by the Bessemer process.

[1] Class B steel; acid, open-hearth to be used for tank plates.

II. Chemical Properties and Tests

Chemical Composition

3. The steel shall conform to the following requirements:

Elements considered	Class A steel	Class B steel	Class C steel
Phosphorus, maximum, per cent:			
Basic open-hearth	0.04	0.06	0.04
Acid, open-hearth	0.06	0.08	0.04
Bessemer	....	0.10	
Sulphur, maximum, per cent	0.06	....	0.045

4. **Ladle analyses.**—To determine whether the material conforms to the requirements specified in Section 3, an analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt. A copy of this analysis shall be given to the purchaser or his representative, if requested.

5. **Check analyses.**—A check analysis of Class A and Class C steel may be made by the purchaser from finished material representing each melt, in which case an excess of 25 per cent above the requirements specified in Section 3 shall be allowed.

III. Physical Properties and Tests

Tension Tests

6. The steel shall conform to the following requirements as to tensile properties:

Properties considered	Class A steel	Class B steel *	Class C steel
Tensile strength, pound per square inch	55,000–65,000	55,000–65,000*	46,000–56,000
Yield point, minimum, pound per square inch	0.5 tensile strength	0.5 tensile strength	0.5 tensile strength
Elongation in 8 inches, minimum, per cent	$\frac{1,400,000\dagger}{\text{tensile strength}}$	$\frac{1,400,000\dagger}{\text{tensile strength}}$	$\frac{1,400,000*}{\text{tensile strength}}$
Elongation in 2 inches, minimum, per cent	22	22	

* See Section 8. † See Section 9.

7. **Yield point.**—The yield point shall be determined by the drop of the beam of the testing machine.

8. **Modification in tensile strength.**—Class B steel may have tensile strength up to 70,000 pounds maximum, provided the elongation is not less than the percentage required for 65,000 pounds tensile strength.

9. **Modifications in elongation.**—(*a*) For material over ¾ inch in thickness, a deduction of 1.0 from the percentage of elongation in 8 inches specified for Classes A and B in Section 6 shall be made for each increase of ⅛ inch in thickness above ¾ inch, to a minimum of 18 per cent.

(*b*) For material under $\frac{5}{16}$ inch in thickness, a deduction of 2.5 from the percentage

of elongation in 8 inches specified for Classes A and B in Section 6 shall be made for each decrease of $\frac{1}{16}$ inch in thickness below $\frac{5}{16}$ inch.

10. **Character of fracture.**—All broken tension test specimens shall show a silky fracture.

11. **Bend tests.**—(*a*) The test specimen for plates, shapes and bars shall bend cold through 180° without fracture on the outside of the bent portion, as follows: For material $\frac{3}{4}$ inch and under in thickness, flat on itself; for material over $\frac{3}{4}$ inch up to $1\frac{1}{4}$ inches in thickness, around a pin the diameter of which is equal to $1\frac{1}{2}$ times the thickness of the specimen; and for material over $1\frac{1}{4}$ inches in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen.

(*b*) The test specimen for pins and rollers shall bend cold through 180° around a 1-inch pin without fracture on the outside of the bent portion.

(*c*) A rivet rod shall bend cold through 180° flat on itself without fracture on the outside of the bent portion.

(*d*) Bend tests may be made by pressure or by blows.

12. **Test specimens.**—(*a*) Tension and bend test specimens shall be taken from the finished rolled or forged product, and shall not be annealed or otherwise treated, except as specified in Section 13.

(*b*) Tension and bend test specimens for plates, shapes and bars, except as specified in paragraph (*c*), shall be of the full thickness of material as rolled, and with both edges milled to the form and dimensions shown in Fig. 35, or may have both edges parallel.

(*c*) Tension and bend test specimens for plates and bars (except eye-bar flats) over $1\frac{1}{2}$ inches in thickness or diameter may be turned or planed to a diameter or thickness of at least $\frac{3}{4}$ inch for a length of at least 9 inches.

(*d*) Tension and bend test specimens for pins and rollers shall be taken parallel to the axis, 1 inch from the surface of the bar. Tension test specimens shall be of the form and dimensions shown in Fig. 36. Bend test specimens shall be 1 inch by $\frac{1}{2}$ inch in section.

(*e*) Rivet bars shall be tested in full-size sections as rolled.

13. **Annealed specimens.**—Test specimens for material which is to be annealed or otherwise treated before use, shall be cut from properly annealed or similarly treated short lengths of the full section of the piece.

14. **Number of tests.**—(*a*) At least one tension test and one bend test shall be made from each melt. If material from one melt differs $\frac{3}{8}$ inch or more in thickness, tests shall be made from both the thickest and the thinnest material rolled.

(*b*) If any test specimen develops flaws, or an 8-inch tension test specimen breaks outside the middle third of the gage length, or if a 2-inch tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted therefor.

(*c*) Material intended for fillers or ornamental purposes will not be subject to test.

IV. Permissible Variations in Weight and Gage

15. (*a*) The sectional area or weight of each structural shape and of each rolled edge plate up to and including 36 inches in width shall not vary more than 2.5 per cent from theoretical or specified amounts.

(*b*) The thickness or weight of each universal plate over 36 inches in width and of each sheared plate shall conform to the schedule of permissible variations for sheared plates, manufacturers' standard practice, appended to these specifications.

(*c*) The weights of angles, tees, zees and channels of bar sizes, and the dimensions of rounds, squares, hexagons and flats, shall conform to the manufacturers' standard practice governing the allowable variations in size and weight of hot-rolled bars.

V. Finish

16. The finished material shall be free from injurious defects, and shall have a workmanlike finish.

VI. Marking

17. The name of the manufacturer and the melt number shall be legibly marked, stamped or rolled upon all finished material, except that each pin and roller shall be stamped on the end. Rivet and lattice steel and other small pieces may be shipped in securely fastened bundles, with the above marks legibly stamped on attached metal tags. Test specimens shall have their melt numbers plainly marked or stamped.

VII. Inspection and Rejection

18. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Painting and insulation.—Black, red, gray, and white are the colors generally employed in protective tank painting. The two latter shades are at present quite generally used, especially on light-oil tanks where it is claimed[1] that evaporation losses are minimized by their application. A reduction of 1, 1½ and 2½ per cent in losses for red and gray respectively, is claimed. Laboratory tests[2] in which small tanks of benzine painted in various gloss-finish colors were subjected to the rays of a powerful arc light for fifteen minutes, show such rapid rises in temperature that there can be no question of the advantage of light colors over dark from an evaporation standpoint. It is obvious, however, that the figures in the appended table are in no sense comparable with those obtained under practical working conditions.

Rise in Temperature of Benzine Stored in Tanks of Various Colors

Color of paint or covering	Rise in temperature °F.
Tin plate (tank plated with tin)	19.8
Aluminum paint	20.5
White	22.5
Light-cream paint	23.0
Light-pink paint	23.7
Light-blue paint	24.3
Light-gray paint	26.3
Light-green paint	26.6
Red iron oxide paint	29.7
Dark Prussian blue paint	36.7
Dark chrome green paint	39.9
Black paint	54.0

[1] Petroleum Gazette, 20 (1915), No. 4, 22. Evaporation loss figures extending over a period of seven years are also tabluated for various crudes in U. S. Bureau of Mines Bulletin 155, p. 65.

[2] Gardner, H. A.: The heat-reflecting properties of colors applied to oil and gas storage tanks. Circular 44, Paint Mfg. Assn. of U. S. Educational Bureau, Sci. sec., January, 1917, p. 1.

In the choice of paints a black graphite, or red iron-oxide-base pigment of excellent quality and permanent in color when exposed to sulphur gases, can easily be obtained from any reputable paint manufacturer. On the other hand it is somewhat difficult to secure a white or gray paint that will stand up under severe conditions without blackening. For this reason a pure white paint is not recommended, but rather a gray varying from off-white to light lead color according to the severity of working conditions. While zinc oxide is the principal pigment in a light-colored paint prepared to withstand sulphur gases,[1] an all-zinc base is not altogether satisfactory, and a certain amount of basic lead sulphate is usually incorporated. If this latter product contains a trace of oxide or carbonate of lead, the paint in which it is employed will eventually darken when exposed to the action of gases containing hydrogen sulphide, such as are evolved in greater or less quantity from the great majority of petroleum intermediates. It would even appear that under unusual conditions a reducing action takes place, so that paint containing lead in any form will gradually darken. Such instances require either a pure zinc-base paint or the adoption of some darker-colored pigment. The following analyses represent paints that can be used without appreciable darkening under all but the severest conditions.

Composition of Paints Usable without Darkening

Formula A (Medium Exposure)

Color: Battleship Gray

	Per cent
Zinc oxide	18
Lead sulphate	09
Magnesian silicate	15
Calcium carbonate	10
Linseed oil	09
Varnish	24
Turpentine and drier	15

Formula B (Severe Exposure)

Color: Battleship Gray

	Per cent
Zinc oxide	29
Lead sulphate	14
Magnesian silicate	05
Coloring pigment	01
Linseed oil	28
Varnish	23

In addition to the painting and use of water-tops, tanks are sometimes equipped with cooling sprays to reduce evaporation. Various coverings, from hair felt to asbestos cement and tile enclosure, are successfully used, the kind of insulation employed being obviously dependent on the results desired. Tile is used where insulation requirements are moderate in nature. It is reported[2] that insulation reduces evaporation losses 4 to 6 per cent. Fig. 37 illustrates a detail of tile casing for a 55,000-barrel tank.

Gasometers.—The shells of all gasometers are built in practically the same manner as tanks. Little description is therefore required beyond the statement that their

[1] Zinc oxide makes an ideal permanent paint base where there is exposure to sulphur gases, since zinc sulphide, if formed, is itself white, and no darkening in color results.

[2] Bulletin 155, U. S. Bureau of Mines, p. 54.

use in saving gases that would otherwise go to waste in periods of overproduction is becoming more general in refineries. The illustration, Fig. 38, gives an excellent idea of the appearance of a gasometer of considerable size installed in a refinery that is operating on Mexican crude.

Cost of steel tanks.—As the cost of steel tanks is computed by the manufacturers on a weight basis, it is obvious that there will be considerable variation in quotations. The following table represents the average erection price of various-sized tanks in different sections of the country. The quotations of competitive firms from a rate standpoint only are considered.

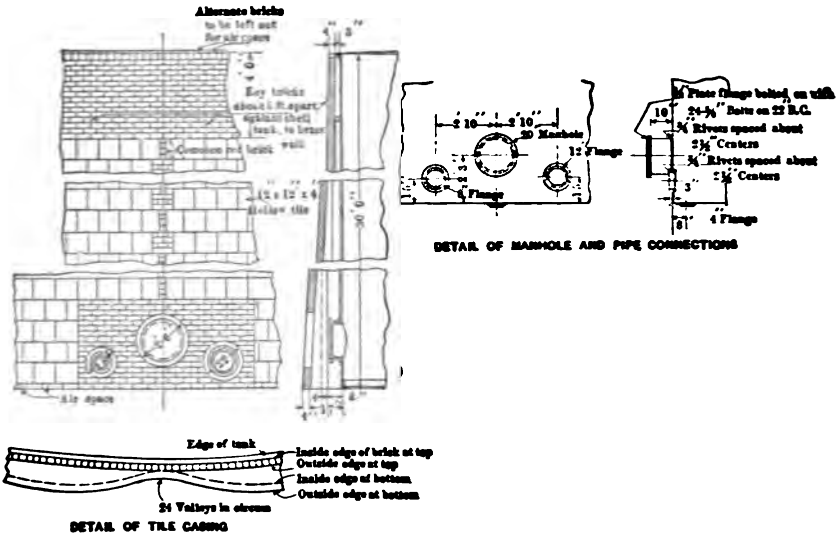


Fig. 37.—Details for a 55,000-barrel tank.

Cost of Steel Tanks Erected *

Size	Roof	Cost erected, Eastern district	Cost erected, Mid-Continent district	Cost erected, Wyoming district	Cost erected, California district
Barrels					
55,000	Steel	$22,500	$26,000	$28,000	$29,500
55,000	Wood	16,600	19,000	20,500	21,400
37,500	Steel	17,000	18,500	20,400	20,000
37,500	Wood	13,200	15,000	16,100	16,800
20,000	Steel	11,300	12,750	13,650	14,250
10,000	Steel	7,300	8,100	8,600	8,900
5,000	Steel	4,050	4,500	4,900	5,000
1,000	Steel	2,000	2,200	2,550	2,400

* Prices effective, May 5, 1921.

Concrete tanks.—While a discussion of the large concrete storage reservoirs so common in the West is not within the scope of this chapter, it might be stated that not a few refineries were forced to install concrete tankage during the war on account of the scarcity and the cost of steel plate. They obtained excellent results with products of low and intermediate gravities. The general inflexibility of this type of tankage

FIG. 38.—Refinery gasometer.

for refinery purposes has already been mentioned, but the low fire risk and the possibility of construction in limited areas make practical an increase in storage, otherwise often impossible.

The construction of concrete tanks is theoretically a simple matter, but it requires a high degree of engineering skill to produce a tank capable of holding, without seepage,

FIG. 39.—Detachable forms for concrete tank construction.

such light-oil products as high-gravity crude, kerosene and gasoline. In the case of the last-named commodity it is questionable whether large absolutely successful tanks have yet been erected. Concrete tankage for heavy crude, fuel oil, gas oil and distillates, on the other hand, have been very generally successful. Often no other finish has been given to the inside of the tank than a neat grout coating, and in some instances even this has been omitted. To construct a tank capable of holding light products, only

a. Excavating for a con crete lined tank.

b. Forms for concrete tank.

c. Completed tank.

Fig. 40.—Progress in construction of concrete tank.

the best materials should be used, and the casting should be as near monolithic as possible. The inner surface should be covered with one or more coats of neat grout, followed by silicate or other special proprietary preparation. To aid in making possible a practically monolithic construction, readily detachable forms are used, which can be easily elevated as the height of the tank progresses. Such tank construction is shown in Fig. 39, other construction in Fig. 40. The dimensions of several concrete tanks that were built for a refinery in Oklahoma are as follows:

Inside diameter, 34 feet.
Inside height, 10 feet.
Thickness of bottom, 5 inches.
Slope of bottom to center, 1 inch to 4 feet.
Thickness, walls, 8 inches.
Thickness, roof, 4 inches.
Slope of roof from cone to eaves, 1 inch to 4 feet.

The height of tanks projecting above the normal ground level is about 3 to 4 feet. The space about the tanks should be back-filled with earth, and the roofs also covered, giving in final construction the appearance of slightly elevated circular mounds.

The appended tentatively recommended practice for concrete tank construction is offered as the latest and most authoritative.

TENTATIVELY RECOMMENDED PRACTICE FOR THE CONSTRUCTION OF CONCRETE FUEL OIL STORAGE TANKS[1]

MATERIALS

Cement.—The cement should meet the requirements of the current standard specifications for Portland cement adopted by the American Society for Testing Materials and this Institute (Standard No. 1). It should be stored in a weather-tight structure with the floor raised not less than 1 foot from the ground. Cement that has hardened or partially set should not be used.

Aggregates.—Before delivery to the work, the contractor should submit to the engineer a 50-pound sample of each of the aggregates proposed for use. These samples should be tested and if found to pass the requirements of the specifications, similar material should be considered as acceptable for the work. In no case should aggregates containing frost or lumps of frozen material be used.

Fine aggregate.—(*a*) Fine aggregate should consist of natural sand or screenings from hard, tough, crushed rock or pebbles consisting of quartz grains or other hard material clean and free from any surface film or coating and graded from fine to coarse particles. When dry it should pass a sieve having 4 meshes per linear inch. Fine aggregate should not contain injurious vegetable or other organic matter as indicated by the colorimetric test, nor more than 7 per cent by volume of clay or loam. Field tests may be made by the engineer on fine aggregate as delivered at any time during the progress of the work. If there is more than 7 per cent of clay or loam by volume in one hour's settlement after shaking in an excess of water the material represented by the sample should be rejected.

(*b*) Briefly, the colorimetric test may be applied in the field as follows: Fill a 12-ounce graduated prescription bottle to the 4½-ounce mark with the sand to be tested. Add a 3 per cent solution of sodium hydroxide until the volume of sand and solution, after shaking, amounts to 7 ounces. Shake thoroughly and let stand for twenty-four

[1] Prepared by Committee on Concrete Storage Tanks of the American Concrete Institute, February, 1920. (From Proceedings of the American Concrete Institute, Vol. XVI, 1920.)

hours. The sample should then show a practically colorless solution or at most a solution not darker than straw color.

Coarse aggregate.—Coarse aggregate should consist of clean, hard, tough, crushed rock or pebbles graded in size, free from vegetable or other organic matter and should contain no soft, flat or elongated particles. The size of the coarse aggregate should range from 1 inch down, not more than 5 per cent passing a screen having 4 meshes per linear inch, and no intermediate sizes should be removed.

Mixed aggregate.—Crusher-run stone, bank-run gravel or mixtures of fine and coarse aggregates prepared before delivery on the work should not be used because the ratio of fine to coarse material varies so widely as to lead to concrete mixtures of greatly varying proportions.

Water.—The water should be free from oil, acid and injurious amounts of vegetable matter, alkali or other salts.

Reinforcement.—The reinforcing metal should meet the requirements of the current standard specifications for billet steel reinforcement of the American Society for Testing Materials excepting that cold twisted square bars should not be employed in the construction. Reinforcing should be free from excessive rust, scale, paint or coatings of any character which would tend to reduce or destroy the bond.

Proportions

Unit of measure.—The unit of measure should be the cubic foot. Ninety-four pounds (1 sack or ¼ barrel) of cement should be assumed as 1 cubic foot.

Proportions.—The concrete should be mixed in the proportions by volume of 1 sack of Portland cement, 1½ cubic feet of fine aggregate and (3) cubic feet of coarse aggregate.

Measuring.—The method of measuring the materials for the concrete, including water, should be one which will insure separate and uniform proportions of each of the materials at all times.

Mixing

Machine mixing.—(*a*) All concrete should be mixed by machine (except when under special conditions the engineer permits otherwise) in a batch mixer of an approved type equipped with suitable charging hopper, water storage and a water measuring device which can be locked.

(*b*) The ingredients of the concrete should be mixed to the required consistency and the mixing continued not less than one and one-half minutes after all materials are in the mixer and before any part of the batch is discharged. The mixer should be completely emptied before receiving materials for the succeeding batch. The volume of the mixed material used per batch should not exceed the manufacturer's rated capacity of the drum.

(*c*) The mixing plant should be of sufficient capacity and power to carry out each prearranged operation without danger of delay during the process.

Consistency.—The quantity of water used in mixing should be the least that will produce a plastic or workable mixture which can be worked into the forms and around the reinforcement. Under no circumstances should the consistency of the concrete be such as to permit a separation of the coarse aggregate from the mortar in handling. An excess of water should not be permitted as it seriously affects the strength of the concrete, and any batch containing such an excess should be rejected.

Retempering.—The retempering of mortar or concrete which has partially hardened, that is, remixing with or without additional materials or water, will not be permitted.

Reinforcement

Placing.—Reinforcing steel should be cleaned of all mill and rust scales before being placed in the forms. All reinforcement should be bent or curved true to templates, placed in its proper position as required by the plans and securely wired or fastened in place, well in advance of the concreting. Reinforcement should be inspected and approved by the engineer before any concrete is deposited.

Splicing.—Wherever it is necessary to splice the reinforcement, no lap-splice should be less than forty diameters. No two laps of adjacent rods should be directly opposite each other in circular walls.

Depositing

General.—(*a*) Before beginning a run of concrete all hardened concrete or foreign material should be completely removed from the inner surfaces of all conveying equipments.

(*b*) Before depositing any concrete, all debris should be removed from the space to be occupied by the concrete, all steel reinforcing should be secured in its proper location, all forms should be thoroughly wetted except in freezing weather, unless they have been previously oiled, and all formwork and steel reinforcing should be inspected and approved by the engineer.

Handling.—Concrete should be handled from the mixer to the place of final deposit as rapidly as possible and by methods of transporting which would prevent the separation of the ingredients. The concrete should be deposited directly into the forms as nearly as possible in its final position so as to avoid rehandling. The piling up of concrete material in the forms in such manner as to permit the escape of mortar from the coarser aggregate should not be permitted. Under no circumstances should concrete that has partially set be deposited in the work.

Depositing.—(*a*) Where continuous placing of concrete in floor and walls is impracticable, the operation should be in the following order:

1. The concrete of footings and floor.
2. The concrete of walls.
3. The concrete of columns, if any.
4. The concrete of the roof.

(*b*) No break in time of over forty-five minutes should occur during any one operation except between columns and supported roof slabs where six hours should elapse to permit the settlement of concrete in the columns. In placing concrete in floors, it should not be allowed to set up on exposed vertical faces where work is temporarily discontinued. Column footings should be placed monolithically with floor and the floor reinforcement so designed as to distribute the column load over a sufficient area.

(*c*) In walls the concrete should be placed in layers of not over 12 inches for the entire wall so that a monolithic structure will result. The concrete should be thoroughly worked around the reinforcing material so as to completely surround and embed the same.

(*d*) If the placing of concrete is unavoidably interrupted by accident or otherwise, the previous surface should be roughened and washed clean with a hose, a mixture of 1:1 mortar slushed on uniformly before further concreting is done and the new concrete should be deposited immediately thereafter.

(*e*) When deposited in the forms, concrete should be thoroughly spaded against the inner and outer faces of the forms so that it will densely compact and force out the

trapped air and work back the coarser particles from the face of the forms. More and better work can be accomplished by using light wooden sticks 1 by 2 inches, planed smooth with sheet steel blade at lower end rather than with heavy spades. Enough laborers should be employed, spading continuously, to obtain satisfactory results.

Depositing concrete during freezing weather.—(*a*) During freezing weather, the stone, sand or water or all three materials should be heated so that the concrete mixture will have a temperature of at least 60° F. After concrete is deposited, precaution should be taken to prevent freezing for at least forty-eight hours. Concreting should not be begun when the temperature is below 15° F.

(*b*) The tank should not be placed in service until after the engineer in charge of the work is assured that the concrete has gained sufficient strength to resist all involved stresses.

Finishing

The floor and roof should be brought to grade with a straight edge or strike board, finished with a wood float and troweled to a smooth surface as soon as possible after the concrete is deposited. Voids in walls, if any, should be filled with a 1:1½ mortar as soon as the forms are removed.

Forms

Material.—The forms should be of good material, planed to a uniform thickness and width, tongued and grooved for walls, strongly made and located or held in place by exterior bracing or on the outside or circular walls by circumferential bands so that no distortion allowing displacement of concrete is possible.

Workmanship.—Joints in forms should be tight so that no mortar will escape. If forms are to be re-used, they should be thoroughly cleaned. A slush mixture of ½ petrolatum and ½ kerosene makes a good mixture for oiling forms. The use of bolts or wires through the concrete should be prohibited.

Removal.—The forms should not be removed until the concrete has sufficiently hardened so that no deflection or damage will result. In warm weather column and wall forms should remain undisturbed for at least forty-eight hours and roof forms at least seven days. In cold weather no predetermined rules can be made.

Sliding forms.—Contractors equipped to handle the work with sliding forms may be permitted to do so provided the forms are left at one level until the concrete which wiil be exposed on raising them has hardened sufficiently to sustain the weight of the concrete above.

Details of Construction

Joints.—Unless the roof is insulated against temperature changes by sufficient earth cover, or the reinforcing in walls and roof is designed to take care of temperature stresses likely to occur, an expansion joint should be provided between the tops of walls and the bottom of roof slabs so that any expansion of the roof due to temperature will not transmit bending moment into the walls.

(*b*) In roof slabs where temporary stops are necessary they should be made on the plane of least shear, that is at the middle of beams or slabs.

(*c*) If walls and floor are not deposited in one operation an approved joint or dam should be provided between the floor and walls. It can be made as follows: (1) Provide a recess in the floor to engage the wall and insert a galvanized iron strip about 8 inches wide with joints soldered and riveted so as to form a continuous band on one side of the recess, or, (2) place a 10-inch strip of deformed sheet metal 1 inch back from the inside form and engaging both floor and wall, and after the wall form is removed the 1-inch recess is to be plastered with a 1:1½ mortar to make a 6-inch coved base.

Treatment of concrete surface.—As some owners will insist on a guarantee of oil tightness for a term of years and as contractors who figure work on a contract basis in competition will not usually guarantee work designed by others, it may be found desirable to use an oilproof skin coating regardless of the density of the oil to be stored.

Backfilling.—Backfilling should not be done around the walls nor deposited on the roof until in the opinion of the engineer in charge, it can be done safely.

Venting of tanks.—(*a*) An independent, permanently open galvanized-iron vent terminating outside of building shall be provided for every tank.

(*b*) Vent openings should be screened (30 by 30 nickel mesh or its equivalent) and shall be of sufficient area to permit proper inflow of liquid during the filling operation and in no case less than 2 inches in diameter. Vent pipes shall be provided with weatherproof hoods, and terminate 12 feet above the top of fill pipe, or, if tight connection is made in filling line, to a point 1 foot above the level of the top of the highest reservoir from which the tanks may be filled and never within less than 3 feet measured horizontally and vertically from any window or other building opening.

Tanks with a capacity of 500 gallons or less may be provided with a combination fill and vent fitting so arranged that fill-pipe cannot be opened without opening the vent pipe.

(*c*) Where a battery of tanks is installed, a vent pipe may connect to a main header, but individual vent pipes shall be screened between tank and header. The header outlet shall conform to the foregoing requirements.'

Filling pipe.—The end of the filling pipe in the tank shall be turned up so as to form a trap or seal, and when installed in the vicinity of any door or other building the opening shall be as remote therefrom as possible, so as to prevent the liability of flow of oil through the building openings. The terminal shall be outside of the building in a tight, incombustible box or casting, so designed as to make access by unauthorized persons difficult.

Manhole.—Manhole covers shall be securely fastened in order to make access by unauthorized persons difficult. No manhole should be used for filling purposes.

Test well or gaging device.—A test well or gaging device may be installed, provided it is so designed as to prevent the escape of oil or vapor within the building at any time. The top of the well should be sealed and where located outside of a building, kept locked when not in use. Where indicating devices are used, they should be connected to substantial fittings that will minimize the exposure of oil. No device should be used, the breakage of which will allow the escape of oil.

Pipe-fittings.—If pipes pass through the walls they should be flanged sections with a space of about 1½ inches left between the flange and the concrete on each side of the wall; this space should be caulked later with litharge and glycerin or other approved oilproof material. It is advisable also to have a ring projecting about 2 inches around the pipe sleeve which engages the concrete.

Care of surface water.—(*a*) In many cases it becomes necessary to construct reinforced concrete tanks in localities near tidewater, rivers, streams or water basins where water pressure may be derived through porous soils. Care should be taken to keep this water pressure from fresh concrete until it has attained sufficient strength to fully resist the assumed hydrostatic pressure.

(*b*) One or more sumps should be provided and the floor should be underdrained so that water will flow freely to the sump. Suitable pumping facilities should be provided so that water can be pumped continuously. A flange pipe projecting just above the floor may be built into the concrete and the top of the the pipe covered with a cap to be bolted or screwed down when pumping is no longer considered necessary.

(*c*) If it becomes necessary to sheet-pile or shore the tanks, the shores should be so

designed that they will not pass through the walls and thus leave openings that it would be necessary to fill later.

Cleaning out tanks—Warning.—It is dangerous to life to enter fuel oil tanks soon after they are opened. There is danger of suffocation from oil fumes on account of the absence of sufficient oxygen. Therefore, it should be required that all manhole covers be left off to admit complete diffusion before workmen enter. To accelerate this diffusion the use of a compressed air line is advised.

Tank measurements.[1]—The methods used by the various oil companies in obtaining the data necessary for computing the volumes of oil tanks and reservoirs, and for preparing gage tables are practically the same, differing only in minor details. As regards steel tanks there is much discussion as to just how many circumference measurements are necessary for accurate work. Some companies take only two (for a six-ring tank), the lower one being at the middle of the second ring and the upper as near as practicable to the middle of the top ring. Other companies "strap"[2] above each seam, and take one measurement 6 inches below the top of the tank, and one near the bottom just above the bottom row of rivets. However, it has been found that in measuring steel tanks of standard size a surprisingly small variation in results will be obtained if circumference measurements are taken on each ring, or if only the top and bottom rings are measured and the circumference of the others computed. On the other hand, tanks on poor foundations which cause them to be "out of round" and produce bulging uneven sides may require a large number of measurements to insure accuracy.

The outside measurements should be taken in feet and hundredths, the most convenient form in which to have the data for computations. Measurements of deadwood by which is meant all material inside the tank that displaces oil, such as roof supports, blocking, steam coils, and water draw-off pipes, are usually more conveniently taken in feet and inches, as the parts mentioned usually consist of standard-sized timbers and pipes.

The circumference measurements are taken as nearly as possible in the center of each course with the exception of courses 4 and 5 (counting from the bottom upward), which can be more accurately calculated by interpolating between the girths of courses 3 and 6 than by actual measurement. The circumference of the top course is taken by reaching down over the eaves of the tank, the tapeman lying face down on the roof.

If possible, inside measurements should be taken before any oil is put into the tank. Outside measurements should be taken when the tank is full of oil.

After one set of dimensions has been taken it is checked by taking a second set in exactly the same manner. The maximum permissible difference in these two sets of measurement should not be more than 1 in 10,000. The following paragraphs are devoted to the meaning of terms.

Height of tank.—The height of a tank for strapping purposes is the distance between the top of the bottom plate of the tank and the top of the horizontal leg of the top angle iron.

Horizontal segment.—By the horizontal segment is meant the part of the tank shell, less the vertical lap, which encroaches on the area inclosed by a circle, the plane of which is parallel to the tank bottom and the diameter of which is equal to the inside diameter of the tank. The horizontal segment is approximately equal in area to the triangle made by the tap end the tank shell. The horizontal segment is not considered

[1] Adapted from Computing Volume of Tanks and Reservoirs and Preparing Gage Tables, Bureau of Mines, Bulletin 155, page 59.

[2] A term in general use among oil operators, originally meaning the girthing of tanks with a measuring tape, but in modern diction including the whole operation of obtaining the necessary field data for computing the volume of tanks and other fluid receptacles.

at all by many operators and by others is used only when very accurate results are required.

Thickness of sheets.—The thicknesses of the sheets in the various rings can usually be most accurately and most easily determined from the specifications of the tank.

Deadwood.—The swing pipe and fittings and the water draw-offs in the bottom of the tank are usually omitted for the reason that they are always full of oil or water whenever a gage of the tank is taken, and the metal of which they are composed will at most displace only a small volume of liquid. To guard against the possibility of the swing pipe being empty or only partly filled when a gage of the tank is taken, some companies install on the shell of the tank about 2 feet from the swing-pipe nozzle a 2-inch flange having its center line on approximately the same horizontal plane as the center line of the nozzle. A 2-inch pipe connection containing a valve is then placed between this flange and the nozzle, so that oil may be admitted from a point near the bottom of the tank into the bottom of the swing pipe whenever desired. Sand lines are also omitted. However, if there are steam coils in the tank, their volume must be deducted.

Manhole.—The dimensions of the manhole should be determined, as also its position, as the volume of oil that it contains must be added to the volume of the tank.

Corrugated iron and wooden tanks.. As regards corrugated-iron tanks, which are usually of small diameter, the circumference measurements are obtained with the tape lying in the valley of the corrugation. The depth of the corrugation and the distance between corrugations are noted.

In strapping wooden tanks with sloping sides, the thickness of the staves is taken at a number of places about the circumference, and an average thickness determined. The height is obtained by placing a gage rod inside the tank and measuring the vertical height to the top of the staves. The circumference strappings are taken at intervals of 2 feet, measured along the slope of the tank, beginning 6 inches from the bottom.

Computing gage tables for tanks.—From the circumference of each course the outside diameter of that course is computed, and by subtracting twice the thickness of the metal the inside diameter is determined, giving a value from which the gross area of the course is determined. From this is subtracted one-half the area of the vertical laps and the area of the horizontal segnents, giving the net area (plus the deadwood). As the circumference is measured approximately in the center of the sheet, the net area value is considered to be a mean area for the course.

The volume in barrels per course, including the deadwood, is then calculated and, the volume in barrels per ¼ inch per course. Next the volume of the deadwood per course is determined and the volume of the deadwood per ¼ inch per course. Then a table is prepared showing the quantity in barrels to be added for each ¼ inch proceeding from the bottom of the tank upward. The construction of the gage table then resolves itself into the summation of the proper increments. If it were desired to have the gage table read to ⅛ inch the same method of computation would be pursued. In buying and selling crude oil it is customary to read the gage tape to the nearest ⅛ inch and interpolate in the table to find the correct volume.

Each step in the computations should be carefully checked. One-fourth of an inch totals must equal the totals for courses calculated by subtracting the volume of the total deadwood in the course from the total volume of the course, and totals of courses must agree with a separate computation for the whole tank in which figures for total tank volume and total deadwood are used.

As a final check on the whole work, a second man is required to make an independent calculation not quite so complete as the first but one that must check the total contents of each course and the total contents of the tank. Gage tables are made to read to the nearest one-hundredth of a barrel.

Tank measurements.—The following formulae have been selected with a view to facilitating the quick working out of the size of sketch plates, globe roof plates, cone segments, dished ends, etc., as well as the volume for such tankage in gallons and barrels.

Properties of the Circle

Circumference, $C=2\pi r=\pi D.$

Diameter, $D=\dfrac{C}{\pi}=C\times 0.3183=2r.$

Arc, $a=\dfrac{\pi r A^\circ}{180}=0.01745\, rA^\circ.$

Angle, $A=\dfrac{180^\circ a}{\pi r}=57.2958\dfrac{a}{r}.$

Radius, $r=\dfrac{4b^2+c^2}{8b}.$

Diameter, $d=\dfrac{4b^2+c^2}{4b}.$

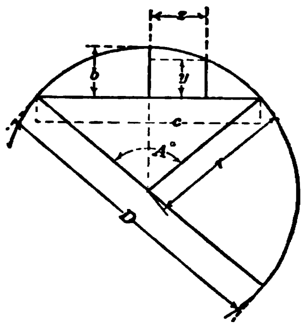


FIG. 41.

Chord, $c=2\sqrt{2br-b^2}=2r\sin\dfrac{A^\circ}{2}.$

Rise, $b=r-\frac{1}{2}\sqrt{4r^2-c^2}=\dfrac{c}{2}\tan\dfrac{A^\circ}{4}=2r\sin^2\dfrac{A^\circ}{4}.$

Rise, $b=r+y-\sqrt{r^2-z^2},\qquad y=b-r+\sqrt{r^2-z^2},$

$z=\sqrt{r^2-(r+y-b)^2}.$

π, $\pi=3.1416.$

Areas of Plane Surfaces

Triangle, Base $\times\frac{1}{2}$ perpendicular height.

$\sqrt{s(s-a)(s-b)(s-c)}.$

$s=\frac{1}{2}$ sum of the three sides a, b and c.

Parallelogram, Base $\times$ perpendicular height.

Circle, $\pi r^2=0.7854\times D^2=0.07958\times c^2.$

Sector of circle: $\dfrac{\pi r^2 A^\circ}{360}=0.008727\, r^2A^\circ=a\times\frac{1}{2}r.$

Segment of circle, $\dfrac{r^2}{2}\left(\dfrac{\pi A^\circ}{180}-\sin A^\circ\right).$

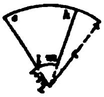
Circle of same area as square, $D=\text{side}\times 1.1284.$

Square of same area as circle, Side $=D\times 0.8862.$

Ellipse, Long $D\times$short $D\times 0.7854.$

Application

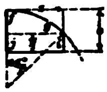
Area sector plate *ehlm*, $\frac{\pi A^\circ}{360}(r^2-r_1^2)$.



$0.008727A^\circ(r^2-r_1^2)$.

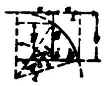
$\frac{1}{2}(\text{arc } eh\times r-\text{arc } lm\times r_1)$.

Area sketch plate, *fgij*, $\frac{r^2}{2}(.01745\,A^\circ-\sin A_1^\circ\cos A_1^\circ)+zy$.



$\frac{\text{arc } fg\times r-(r-b+y)z}{2}+zy$.

Area sketch plate, *ghi*, $\frac{r^2}{2}(.01745\,(A^\circ-A_1^\circ)-\sin A^\circ\cos A^\circ+\sin A_1^\circ\cos A_1^\circ)-zy$.



$\left(\frac{(\text{arc } gh-z_1)r+bz_1+yz}{2}\right)-zy$.

Surface and Volume of Solids

S = Lateral or Convex Surface. V = Volume

Parallelopiped, S = Perimeter, P, perpendicular to sides $\times$ lateral length, l: Pl.
V = Area of base, $B\times$perpendicular height, h : Bh.

Cylinder, right or oblique, circular or elliptic,

S = Perimeter of base, $P\times$perpendicular height, $h=Ph$.
V = Area of base, $B\times$perpendicular height, $h=Bh$.

Pyramid or cone, right and regular,

S = Perimeter, of base, $P\times\frac{1}{2}$ slant height, $l=\frac{1}{2}\,Bl$.
V = Area of base, $B\times\frac{1}{3}$ perpendicular height, $h=\frac{1}{3}\,Bh$.

Frustum of pyramid or cone, right and regular, parallel ends,

S = (sum of perimeter of base, P, and top, b) $\times\frac{1}{2}$ slant height, l : $\frac{1}{2}l(P+b)$.

V = (sum of areas of base, B, and top, b) + square root of their products $\times\frac{1}{3}$ perpendicular height, h : $\frac{1}{3}h$ $(B+b+\sqrt{Bb})$.

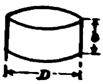
Prismatoid, $V=\frac{1}{6}$ perpendicular height, h (sum of areas of base, B, and top, b, $+4\times$area of section, M, parallel to bases and midway between them. $\frac{1}{6}\,h(B+b+4M)$

Sphere, $S=4\pi r^2=\pi d^2=3.1416\,d^2$;
$V=\frac{4}{3}\pi r^3=\frac{1}{6}\pi d^3=0.5236\,d^3$.

Spherical segment, $S=2\pi rb=\frac{1}{4}\pi(4b^2+c^2)$;
$V=\frac{1}{3}\pi b^2(3r-b)=\frac{1}{24}\pi b(3c^2+4b^2)$.

Application

Tank ring,

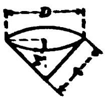


$S = \pi Dh.$

$= Ch.$

Cone bottom,

$h = \frac{\tan A° D}{2}.$

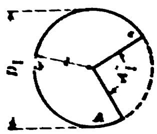


$l = \frac{D}{2 \cos A°}.$

$S = \frac{\pi D l}{2}.$

Layout cone bottom

$D = 2l = \frac{D}{\cos A°}.$

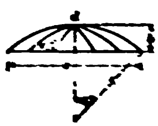


Arc abc: $\pi D = 2\pi l \cos A°.$

$A_1° = 360\frac{(D_1 - D)}{D_1}.$

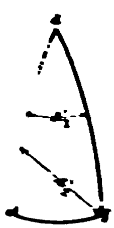
Globe roof (total plates)

$S = 2\pi rb.$



$\frac{1}{4}\pi(4b^2 + c^2).$

Layout globe roof plates in number (N),



Arc $df = .01745\, rA°.$

Arc $de = .01745\, rA°.$

Arc $cf = \frac{2\pi\sqrt{2br - b^2}}{N}.$

$A_1° = \frac{360°}{N}.$

$A_2° = S\frac{0.01745\, r^2}{.0349\, r^2}(180 - A_1°).$

Single plate,

$s = \frac{2\pi rb}{N}.$

$0.01745\,(2A_2° - A_1° - 180°).$

Contents vertical cylinder tanks (dimensions in inches)

$V = D^2 \times 0.0034 =$ U. S. gallons per inch.

$D^2 \times 0.00283 =$ British Imp. gallons per inch.

Contents vertical cylinder tanks (dimensions in feet)

$V = D^2 \times 0.0117 = 42$ U. S gallon-barrels per inch.

$D^2 \times 0.00979 = 50$ U. S. gallon-barrels. per inch.

$C^2 \times 0.0496 =$ U. S. gallons per inch.

$C^2 \times 0.0413 =$ British Imp. gallons per inch.

$C^2 \times 0.00118 = 42$ U. S. gallon barrels per inch.

$C^2 \times 0.000992 = 50$ U. S. gallon-barrels per inch.

Contents of cone bottom, of any angle $A°$; any depth h (dimensions in feet)

$V = 7.834\ h(h \cot A°)^2 =$ U. S. gallons.

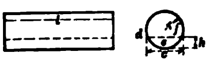
$0.187\ h\ (h \cot A°)^2 = 42$ U. S. gallon-barrels.

Contents dished head, of any radius r; any depth h (dimensions in feet)

$V = 7.834\ h^2(3r - h) =$ U. S. gallons.

$0.187\ h^2(3r - h) = 42$ U. S. gallon-barrels.

Contents horizontal cylindrical tanks of any diameter; any depth h (dimensions in feet)

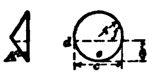


$V = 3.74l\ \ [(\text{arc } del) \times r - (r - h)c] =$ U. S. gallons.

$0.0891\, l[(\text{arc } del) \times r - (r - h)]c = 42$ U.S. gallon-barrels.

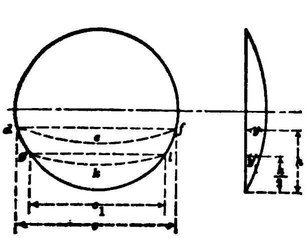
Contents conical end of any angle $A°$; any depth h (dimensions in feet)

$$V = 7.834 \frac{r}{\cot A°}(\text{arc } def \times r - (r - h)c) = \text{U. S. gallons.}$$



$$0.187 \frac{r}{\cot A°}(\text{arc } def \times r - (r - h)c) = 42 \text{ U. S. gallon-barrels.}$$

Contents dished end, of any radius; any depth h (dimensions in feet)



$$V = 0.623h \left[\left(\frac{4y^2 + c^2}{8y} \right) (\text{arc } def - c) + cy + 4 \left(\frac{4y_1^2 + c_1^2}{8y_1} \right) (\text{arc } gki - c_1) + 4c_1 y \right] = \text{U.S. gallons.}$$

Approximate contents dished end, of any radius; and depth h (dimensions in feet)

$$V = 2.492h \left(\left(\frac{4y^2 + c^2}{8y} \right) \text{arc } def + cy \right) = \text{U. S. gallons.}$$

$$\text{Approximate:} \begin{cases} \text{assuming } c_1 = \frac{3}{4}\, c, \\ \text{assuming } y_1 = \frac{3}{4} y, \\ \text{assuming arc } gki = \frac{3}{4} \text{ arc } def. \end{cases}$$

Miscellaneous formulæ, For tables of equivalents see chapter of general tables, page 773.

Pressure of column of oil, any height (h); any gravity (Bé.) in pounds per square inch. (Height in feet.)

$$P = \frac{61.4h}{131.5 + \text{Bé.}°}.$$

STILLS

Crude stills.—Crude stills may be divided into two general classes, horizontal cylindrical and tubular. The vertical cylindrical or cheese-box type, while yet used in large

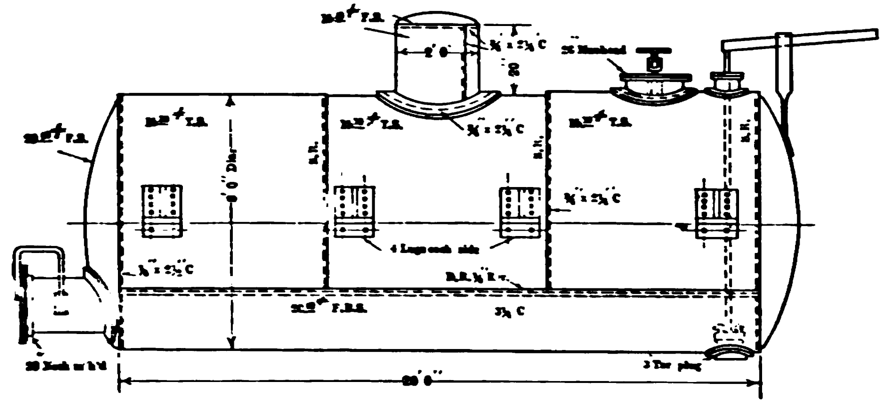


FIG. 42.—A 150-barrel crude still 8 feet by 20 feet.

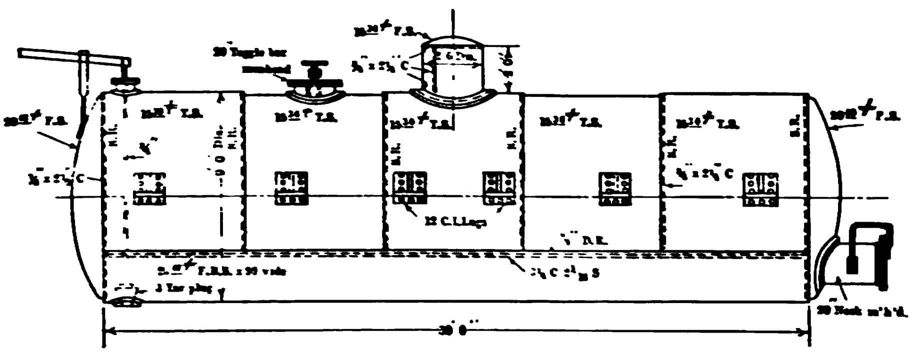


FIG. 43.—A 300-barrel crude still.

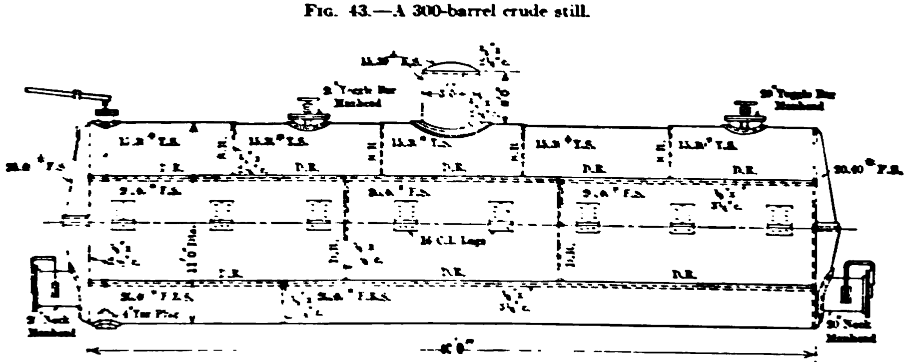


FIG. 44.—A 600-barrel crude still, 11 feet by 40 feet.

units such as a sweetening or steam stills, is practically obsolete for running crude except in some of the older Pennsylvania plants. Horizontal cylindrical crude stills vary in size

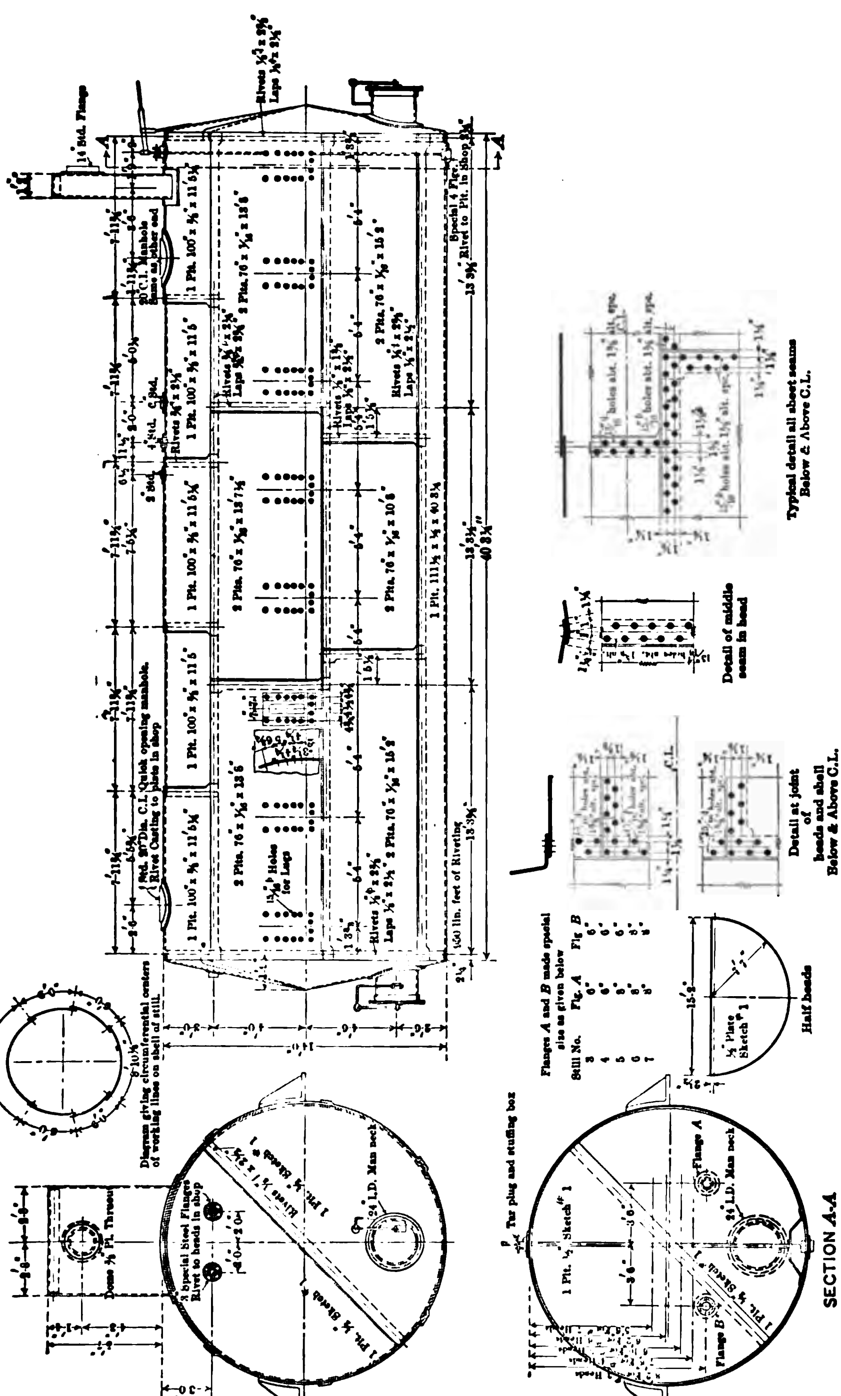


FIG. 45.—Details of a 1000-barrel crude still, 14 feet in diameter by 40 feet in the shell.

from the discard water-tube-boiler steam drum 30 inches in diameter by 15 feet long, to shells of 14 feet diameter by 45 feet long. Even units of 16 feet and 18 feet diameter are in use. Figs. 42, 43 and 44 show the principal dimensions of various sizes, while

FIG. 46.—A finished 600-barrel crude still.

Fig. 45 gives the details of construction of a typical still such as is described under the topic of general plant design. The appearance of such stills is further shown by Fig. 46, which is a standard 600-barrel crude still, fabricated complete in the shop.

FIG. 47.—Battery of four 1000-barrel crude stills nearing completion.

Fig. 47 shows four 1000-barrel stills nearing completion. Fig. 48 illustrates two batteries of ten stills each that are arranged to be fired by automatic stokers.

The essentials in horizontal cylindrical still design are the following: (*a*) to select plate of proper chemical composition and physical constants; (*b*) to specify proper weight sheets; (*c*) to correctly lay out riveting; (*d*) to demand the best workmanship

in every particular. Only still bottom or firebox steel should be selected for the bottom and side sheets, if the latter are subjected to any great heat. Flange steel should be used for lug or side sheets according to conditions, and always for heads. Tank or pressing steel is perfectly satisfactory for upper roundabout courses. In general, a weight of plate should be selected in proportion to the service demanded, as this will secure the best heat transmission with the least construction cost. In practical design this means $\frac{3}{8}$- to $\frac{1}{2}$-inch plate for crude still bottoms, with other weights in proportion. It is sometimes advisable to make lug sheets heavier than bottom sheets, especially in large-sized stills where a comparatively light bottom plate is used. In no case should there be any sharp break (over $\frac{1}{16}$-inch) in the size of the plate between courses, since there will be unequal expansion and danger of the seams opening. While double rivet-

FIG. 48.—Two batteries of ten 1000-barrel stills in construction.

ing of all seams in the bottom, side, and lug sheets is generally practiced to-day in still fabrication, there is some difference in opinion as to the necessity of double-riveting heads on circular seams, since obviously they are not subjected to the direct action of flame. If, however, there is any possibility of the stills being eventually used as coking stills double-riveting is recommended.

Specifications.—In regard to the grades of plate used in still design, reference has been made to Manufacturers' Standard Specifications, a copy of which is appended, and which cover flange, firebox, and rivet steel. Specifications covering tank (structural) steel have already been included.[1]

MANUFACTURERS' STANDARD SPECIFICATIONS, REVISED APRIL 21, 1919

BOILER STEEL

1. **Grades.**—There shall be three grades of steel for boilers, namely: flange, firebox, and boiler-rivet.

I. PROCESS OF MANUFACTURE

2. The steel shall be made by the open-hearth process.

II. CHEMICAL PROPERTIES AND TESTS

3. **Chemical composition.**—The steel shall conform to the following requirements as to chemical composition:

[1] See pages 116 and 121.

Elements considered	Flange steel	Firebox steel	Boiler-rivet steel
Manganese, per cent	0.30 to 0.60	0.30 to 0.50	0.30 to 0.50
Phosphorus, maximum, per cent:			
Basic	0.04	0.035	0.04
Acid	0.05	0.04	0.04
Sulphur, maximum, per cent	0.05	0.04	0.045

4. **Ladle analyses.**—To determine whether the material conforms to the requirements specified in Section 3, an analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt. A copy of this analysis shall be given to the purchaser or his representative.

5. **Check analyses.**—A check analysis may be made by the purchaser from a broken tension-test specimen representing each plate as rolled. This analysis shall conform to the requirements specified in Section 3.

III. Physical Properties and Tests

6. **Tension tests.**—The steel shall conform to the following requirements as to tensile properties:

Properties considered	Flange steel	Firebox steel	Boiler-rivet steel
Tensile strength, pound per square inch	55,000–65,000	52,000–60,000	45,000–55,000
Yield point, minimum, pound per square inch	0.5 tensile strength	0.5 tensile strength	0.5 tensile strength
Elongation, in 8 inches, minimum, per cent	$\frac{1,450,000^*}{\text{tensile strength}}$	$\frac{1,450,000^*}{\text{tensile strength}}$	$\frac{1,450,000}{\text{tensile strength}}$

* See Section 8.

7. **Yield point.**—The yield point shall be determined by the drop of the beam of the testing machine.

8. **Modifications in elongation.**—(*a*) For plates over ¾ inch in thickness, a deduction of 0.5 from the specified percentage of elongation will be allowed for each increase of ⅛ inch in thickness above ¾ inch, to a minimum of 20 per cent.

(*b*) For plates under 5/16 inch in thickness, a deduction of 2.5 from the percentage of elongation specified in Section 6 shall be made for each decrease of 1/16 inch in thickness below 5/16 inch.

9. **Bend tests.**—(*a*) Cold-bend tests shall be made on the material as rolled.

(*b*) Quench-bend test specimens, before bending, shall be heated to a light cherry red as seen in the dark (about 1200° F.), and quenched in water the temperature of which is about 80° F.

(*c*) Specimens for cold-bend and quench-bend tests of flange and firebox steel shall bend through 180° without fracture on the outside of the bent portion, as follows: for material ¾ inch and under in thickness, flat on themselves; for material over ¾ inch up to 1¼ inches in thickness, around a pin the diameter of which is equal

to the thickness of the specimen; and for material over 1¼ inches in thickness, around a pin the diameter of which is equal to 1½ times the thickness of the specimen.

(*d*) Specimens for cold-bend and quench-bend tests of boiler-rivet steel shall bend cold through 180° flat on themselves without fracture on the outside of the bent portion.

(*e*) Bend tests may be made by pressure or by blows.

10. **Test specimens.**—(*a*) Tension- and bend-test specimens for plates shall be taken from the finished product, and shall be of the full thickness of material as rolled. Tension-test specimens shall be of the form and dimensions shown in Fig. 49. Bend-test specimens shall be 1½ inches to 2½ inches wide, and shall have the sheared edges milled or planed.

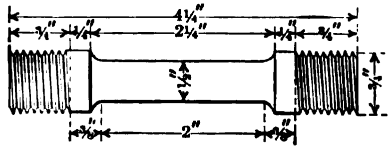


Fig. 49.—Test specimen.

(*b*) The tension- and bend-test specimens for rivet bars shall be of the full size section of material as rolled.

11. **Number of tests.**—(*a*) One tension, one cold-bend, and one quench-bend test shall be made from each plate as rolled.

(*b*) Two tension, two cold-bend, and two quench-bend tests shall be made for each melt of rivet steel.

(*c*) If any test specimen develops flaws, or if a tension test specimen breaks outside the middle third of the gage length, it may be discarded and another specimen substituted therefor.

IV. Permissible Variations in Weight and Gage

12. **Permissible variations.**—(*a*) The thickness or weight of each sheared plate shall conform to the schedule of permissible variations, Manufacturers' Standard Practice.[1]

(*b*) The dimensions of rivet bars shall conform to the Manufacturers' Standard Practice governing allowable variations in the size of hot-rolled bars.

V. Finish

13. **Finish.**—The finished material shall be free from injurious defects, and shall have a workmanlike finish.

VI. Marking

14. **Marking.**—The melt or slab number, name of the manufacturer, grade, and the minimum tensile strength for its grade as specified in Section 6 shall be legibly stamped on each plate. The melt or slab number shall be legibly stamped on each test specimen representing that melt or slab.

VII. Inspection and Rejection

15. **Inspection.**—The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment,

[1] Same as for structural steel specifications, see. p. 121.

and shall be so conducted as not to interfere unnecessarily with the operation of the works.

16. **Rejection.**—Material which, subsequent to the above tests at the mills and its acceptance there, develops weak spots, brittleness, cracks or other imperfections, or

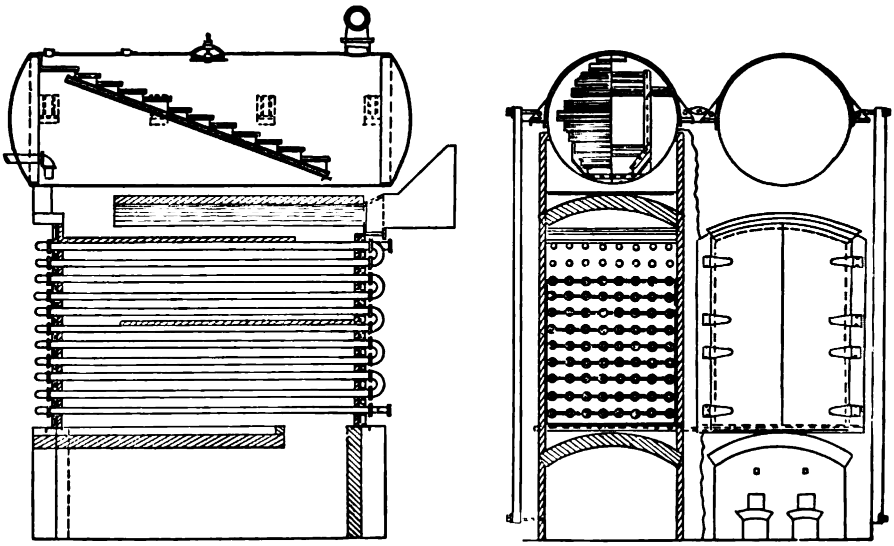


Fig. 50.—A 2500-barrel capacity stripping still.

is found to have injurious defects, may be rejected at the shop, and shall then be replaced by the manufacturer at his own cost.

Tube stills.—While the European internal flue still is not generally employed in this country, the adoption of tube stills, that is, stills where the oil circulates through

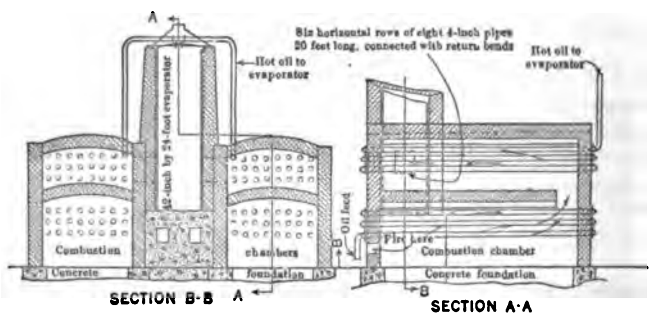


Fig. 51.—General arrangement of furnaces and evaporator, Trumble plant.

heat-surrounded tubes, has been quite general, particularly in the West and South. They are used principally for stripping purposes on crudes which contain moisture not easily separated, and are of low gasoline content, such as California and Mexican crude.

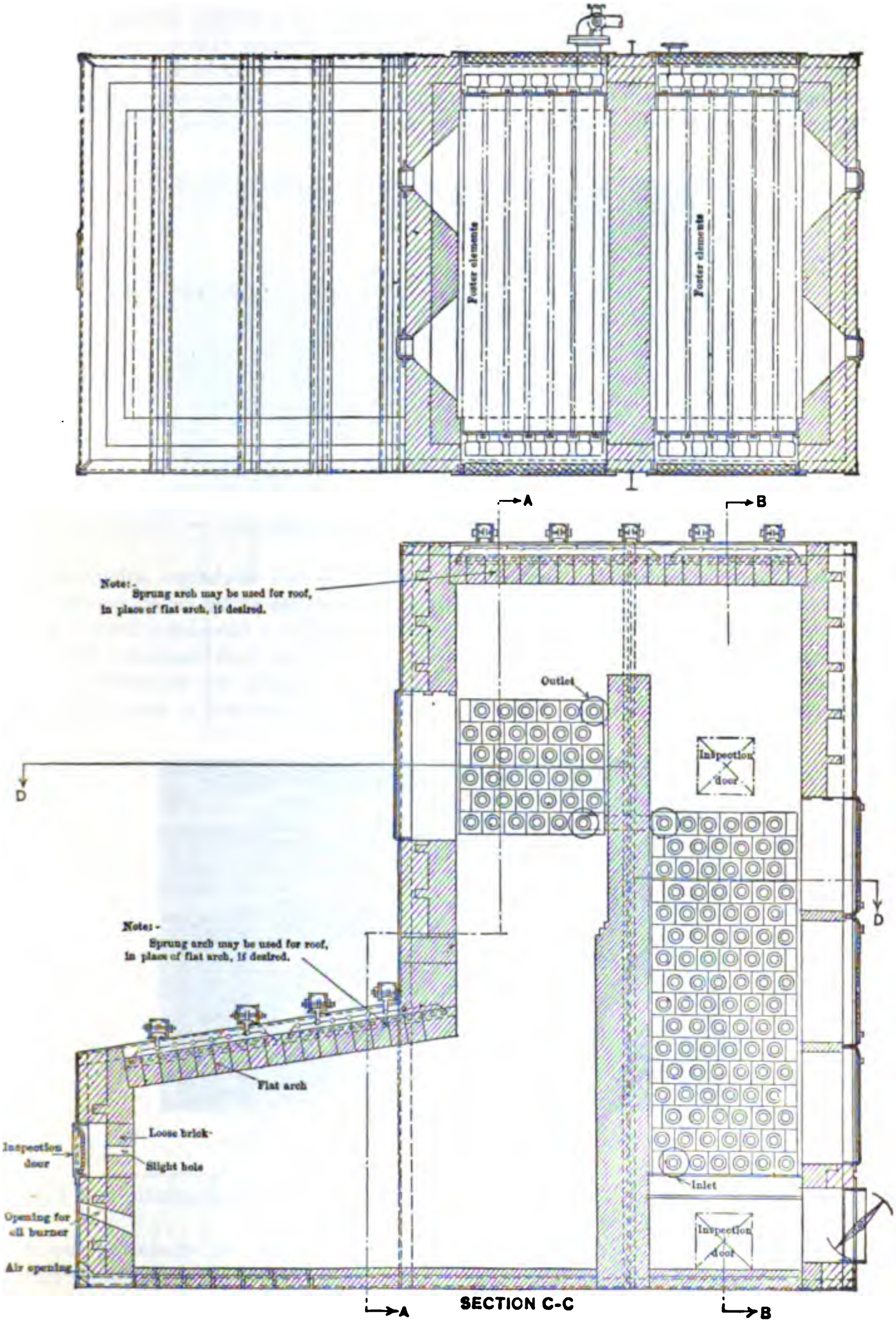


Fig. 52.—Still designed for topping crude oil.

Such stills invariably consist of two distinct parts: (*a*) a tubular heating portion, and (*b*), a tower or shell separating and dephlegmating system. The tubular division usually comprises four to eight rows of 3-inch or 4-inch pipe, in each heating oven, arranged in vertical tiers of four to twelve units per tier. All these are connected by return bends or headers, so as to make one connected system, through which the oil

FIG. 53.—Pipe retorts and evaporator with evaporator column, Trumble plant No. 1, Martinez, Calif.

to be stripped is continually pumped. The end of the coil discharges either into a horizontal cylindrical shell which is provided with film plates where vapors eventually pass through some form of vertical dephlegmating tower, or it discharges directly into a combination separating and dephlegmating tower in the first instance. Various modifications of the tubular still will be further discussed under the topics on general and special refining processes. Figs. 50, 51 and 52 give, however, a very clear idea

FIG. 54.—Second type of heater, Vernon Trumble plant.

of the mechanical design of several general types of tubular topping stills, and Figs. 53 and 54 give views of their appearance.

The essentials in successful tube-still design, apart from the separating towers which are discussed under a succeeding topic, are the following: (*a*), the proper construction of the furnace to secure efficient combustion and uniform distribution of heat over all parts of the heating surfaces; (*b*), the providing of a sufficient number of tubes to secure the maximum efficiency of heat interchange at a commercial speed of

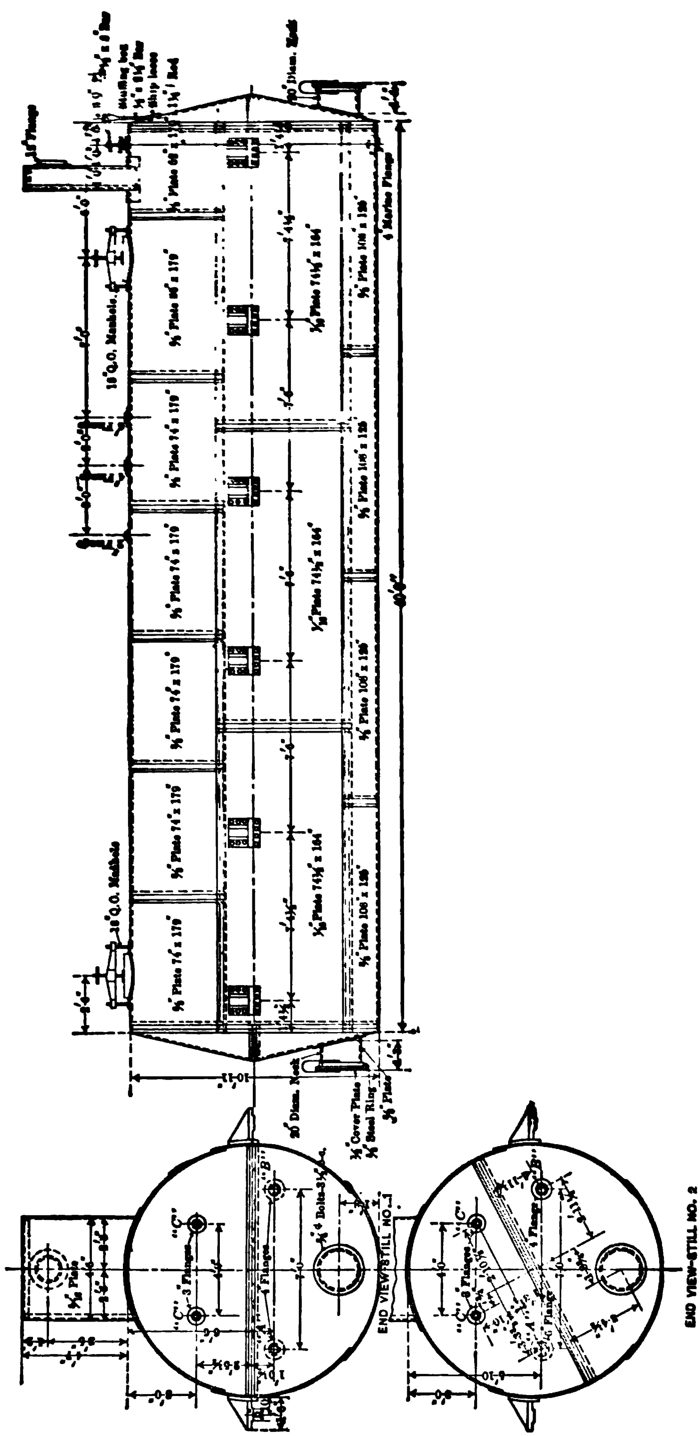
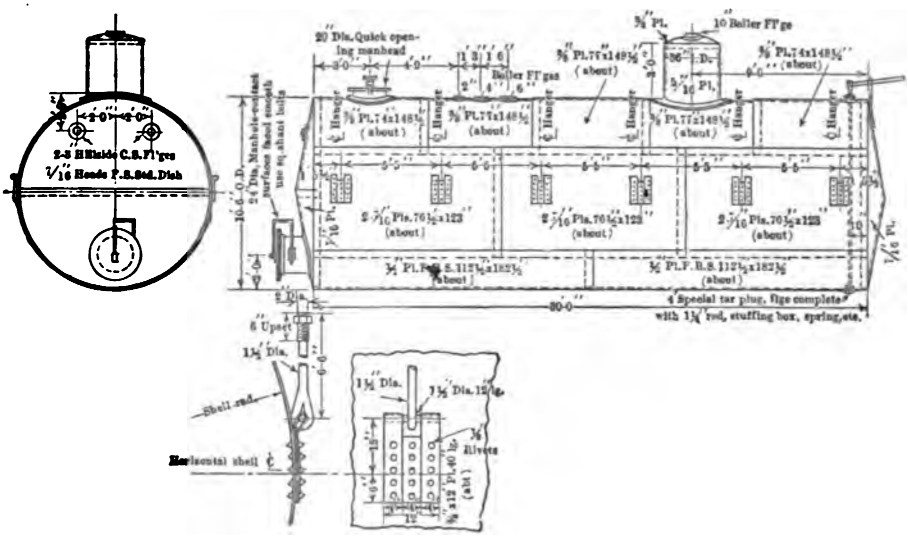


FIG. 55.—Details of a 600-barrel reducing still 11 feet by 40 feet in the shell.

operation which is consistent with the adequate separation of products; and (*c*), the construction of heating surfaces and connections (i.e., tubes, return bends or headers) with a view to requiring minimum labor for cleaning both inside and outside, and also for replacement of defective parts.

Miscellaneous stills.—Rerunning stills should be constructed under the same specifications as crude stills except perhaps that the bottom sheet may be of a slightly lighter plate in special instances. Such units, however, being frequently run dry, are often subjected to severe stresses, particularly if they are used in connection with towers, so that great care should be exercised in fabrication. In fact, as a general rule, crude still specifications should apply throughout.

Reducing stills, being steam-protected with distillation at a lower temperature, may even in the larger sizes have the bottom reduced to $\frac{3}{8}$-inch in thickness. Also flange steel may be substituted for the side sheets with good results. The number



HANGER DETAIL

FIG. 56.—Hanger details of a 450-barrel reducing still.

of supporting lugs may also be less, since in this class of stills distortion is unlikely to occur if they are properly handled. Also the more modern type of suspension setting may be very profitably employed. Details of the construction of a typical 600-barrel reducing still are shown in Fig. 55, page 149. Fig. 56 gives the details of suspension hangers, while a battery of such stills is shown in receding elevation and plan in Fig. 57.

Coking stills require bottoms of $\frac{1}{2}$-inch to $\frac{5}{8}$-inch in thickness, and may, to advantage, have the inside bottom seam electrically welded after riveting, although seams should be avoided as far as possible, particularly in the units that are required to coke reduced crudes or tars. Where this is impossible, butt strap construction becomes necessary. On large units where the crude is coked direct, thereby producing a minimum layer, standard double riveting only is employed. While 14-foot by 40-foot end-fired crude stills are successfully coked, it is generally advisable to decrease the diameter and set for side firing, thereby reducing the thickness of the coke layer, securing greater uniformity in heat distribution, and a corresponding increase in the life of the still. The

European practice of coking in 10-foot diameter cast-iron stills is not practiced in this country. The details of the construction of a still operated in this manner are shown in Fig. 58.

Steam stills, when externally fired, can best be constructed similarly to reducing stills, except that flange steel need only be used on the bottom courses. Such construction is illustrated in Fig. 59. Where no external heat is applied, roundabout

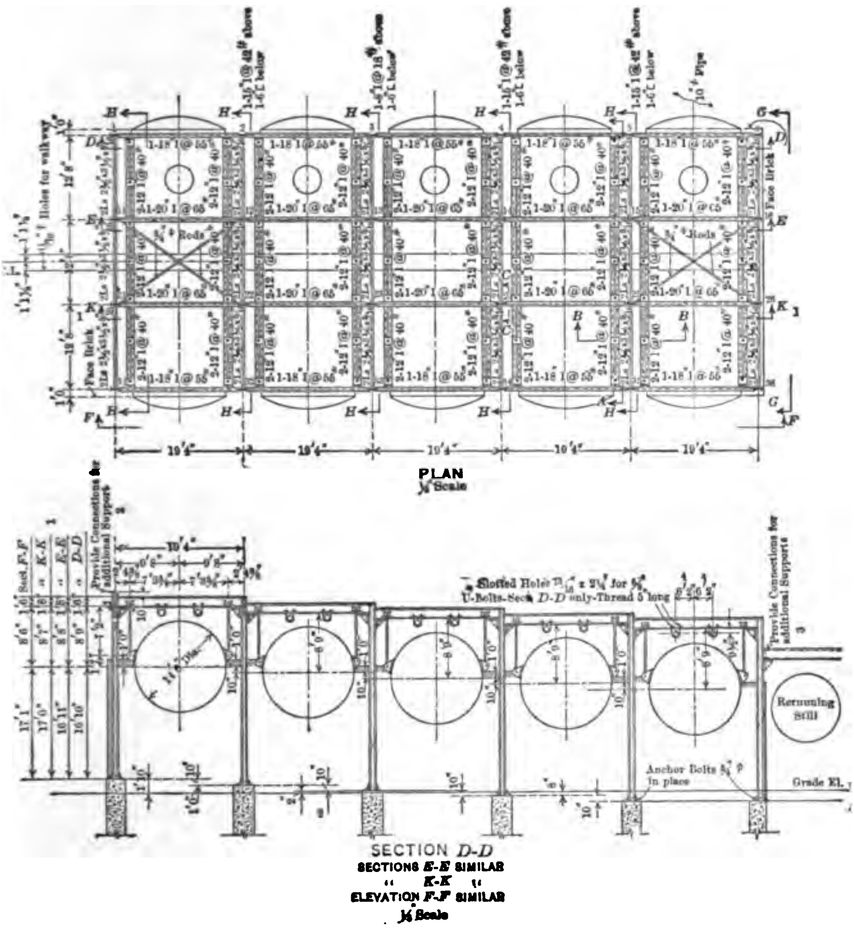


Fig. 57.—Battery of five stills of receding suspension setting.

courses of tank steel make perfectly satisfactory construction. Such types of stills are shown in Figs. 60 and 61. However, as steam stills are sometimes subjected to heavy mechanical stresses on account of rapid changes in steam pressure or in the character of benzine or distillate which is pumped to the system, hemispherical ends may be substituted to advantage[1] over those of the standard dished

[1] With such construction special provisions must be made to insure circulation in the otherwise dead ends.

pattern, in units of the larger sizes. Such construction, together with standard and separating towers, is illustrated in Fig. 62.

Condensers.—The specifications of standard condensers have been covered at length in previous pages. The details of construction for such a type are shown in Fig. 63 (*A* and *B*), with a pumping-out pan in addition, Fig. 64, page 158. The finished appearance of such a box, resting on concrete supports, is clearly shown by Fig. 65, page 159.

In general, the following points should be observed in standard condenser design: (*a*) the proper proportioning of the size of the box for the amount of the product to be distilled; (*b*) the selection of sufficiently heavy plate over and above that necessary from purely engineering considerations to insure a reasonable length of life with allowance for corrosion and scaling; (*c*) determination of the number and size of angle,

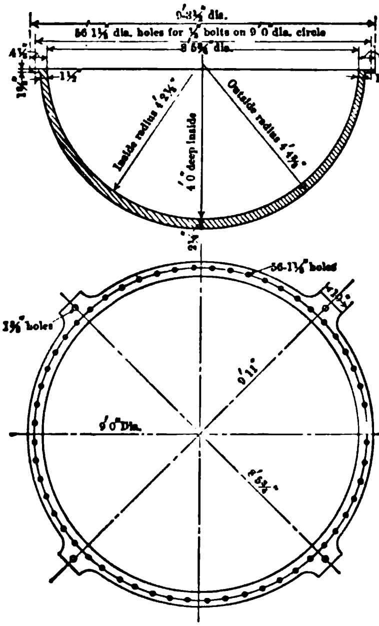


FIG. 58.—Section and flange of cast-iron still bottom (spherical).

T-bars, etc., necessary for reinforcing units, and the radius of the bend of the side sheets at the bottom (if angles are not used). With respect to (*a*), it has been previously shown that for rough purposes, where 14 barrels of water are available per barrel of distillate produced, 50 square feet of condensing surface are required for stripping, 70 square feet for rerunning distillate, and 150 square feet for steam-stilling benzine where both fire and steam are used in the usual proportions in standard practice. From these data the size of worm and the corresponding dimensions of the condenser box can be computed. Even such general methods of calculation are frequently ignored, and the types of boxes that are adopted are supposed to be standard for stills of certain sizes, without regard to the exact quantity of water available. With a plentiful water supply, such procedure is likely to produce more or less efficient operation, but it may involve unnecessary investment. However, where the water supply is limited, or high in temperature, only alarming running losses can result. A con-

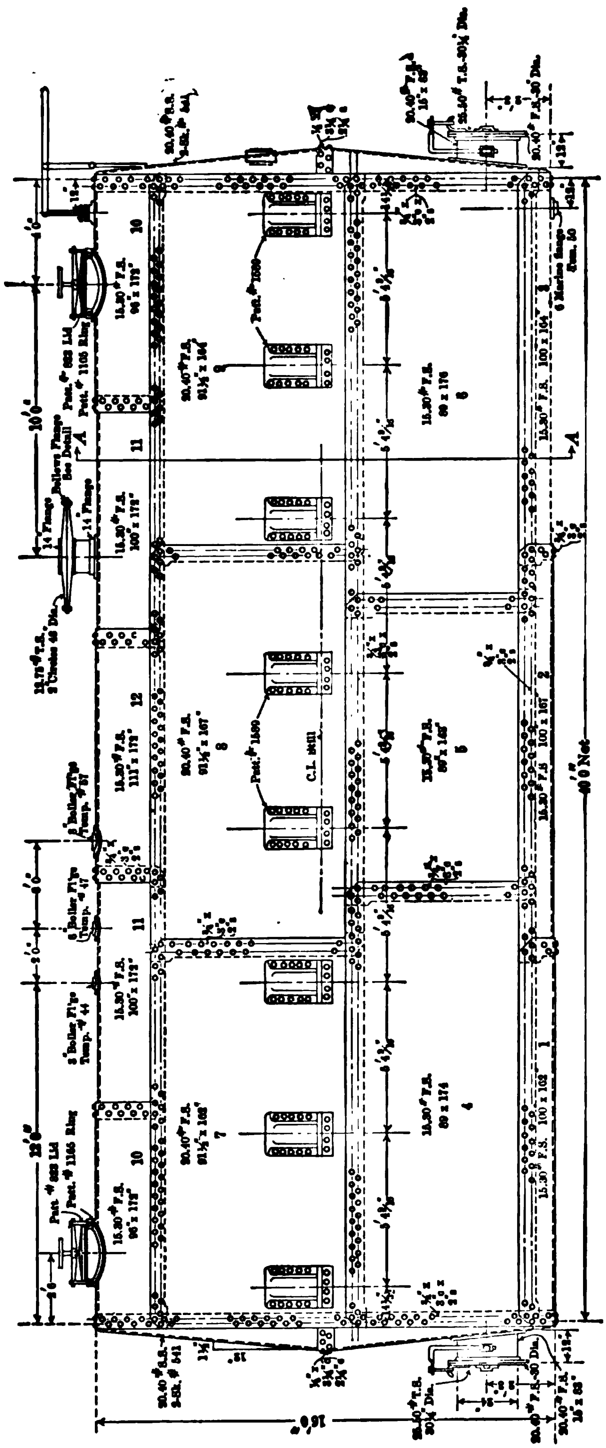


FIG. 59.—Details of a 1500-barrel steam still, 16 feet in diameter by 40 feet long, in the shell.

denser design should therefore involve at least some empirical method of calculation of the condensing surface which is based on the temperature and quantity of the water available, in conjunction with the amount of oil to be distilled. In other words, mere surface allowance is insufficient to guarantee the efficient operation of a plant.

For accurate proportionate design, recourse to a distillation record must be made,

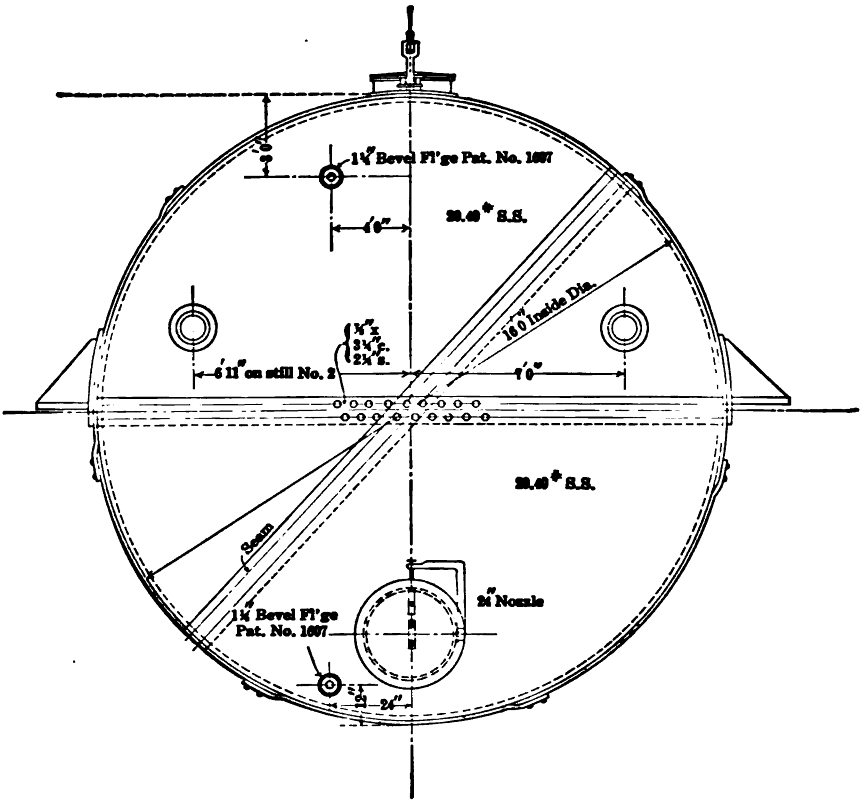


FIG. 59.—Details of a 1500-barrel steam still, 16 feet in diameter by 40 feet long, in the shell.

and from such data together with the temperature and quantity of the water available, the requisite condensing surface can be readily computed. As a typical example, consider a crude of 34.9 Bé. from which it is desired to strip the benzine and kerosene content. The fractionation record is as follows, page 158.

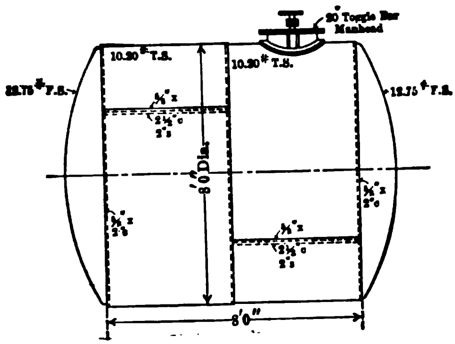


FIG. 60.—A 65-barrel steam still 8 feet by 8 feet.

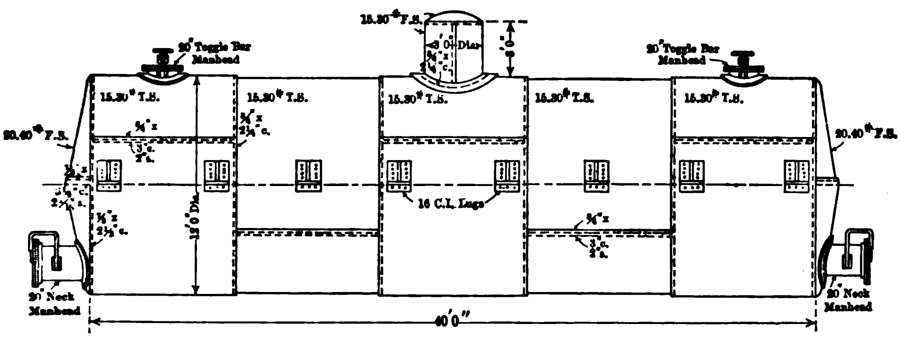


FIG. 61.—A 700-barrel steam still 12 feet by 40 feet.

FIG. 62.—Steam stills and separating towers.

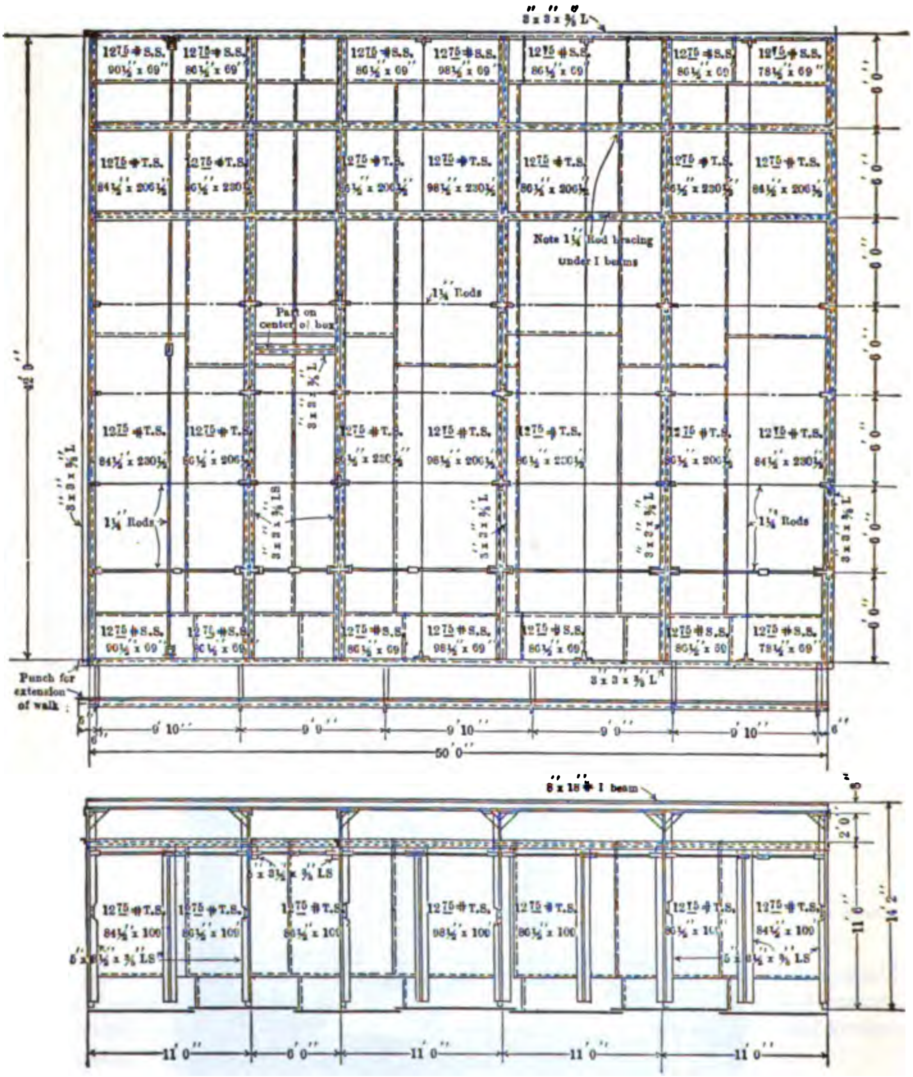


FIG. 63.—(A) Details of a standard condenser.

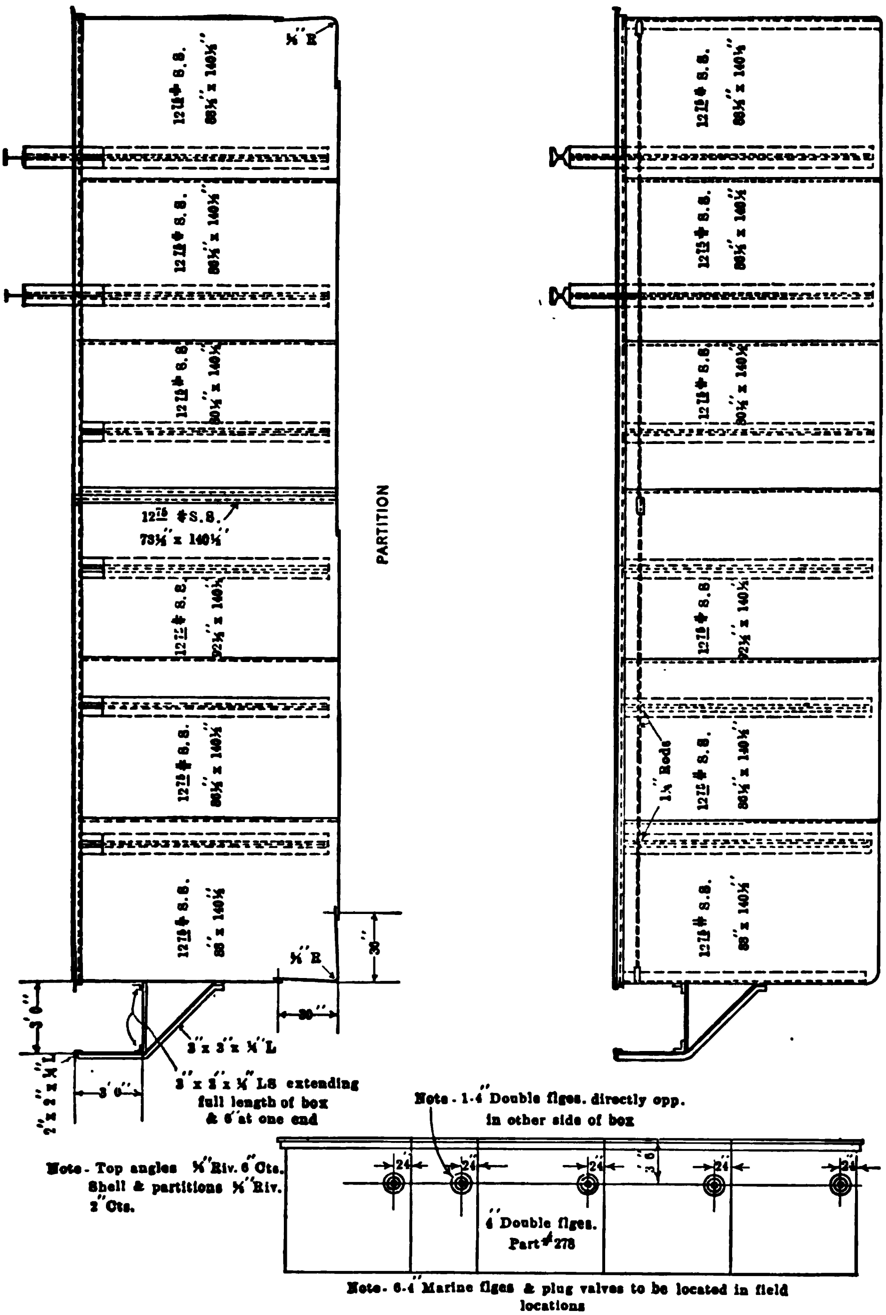


FIG. 63.—(*B*) Details of a standard condenser.

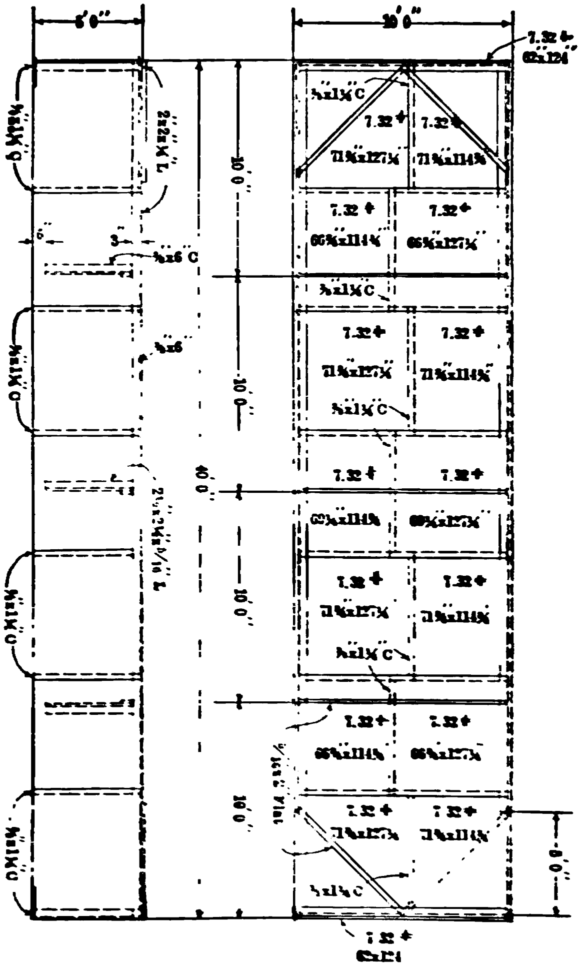


FIG. 64.—Details of a pumping-out pan 40 feet by 10 feet by 5 feet.

Distillation Characteristics of Crude Oil to be Stripped

Boiling point, per cent fraction	Gravity, Bé.	Specific gravity	Yield volume, per cent	Yield per cent by weight
Over 150	79.0	0.67	2.50	1.95
150–200	72.8	0.69	3.10	2.51
200–250	65.1	0.72	6.25	5.25
250–300	57.3	0.75	5.10	4.49
300–350	54.8	0.76	7.50	6.68
350–400	50.4	0.78	8.75	7.96
400–450	45.4	0.80	10.10	9.49
450–500	42.1	0.82	5.30	5.09
500–550	39.3	0.83	7.30	7.08
			55.90	50.50

Assuming that no loss of heat occurs in the vapors from radiation, partial condensation, etc., then the theoretical amount of heat which must be removed from the

FIG. 65.—A 56-foot by 42-foot condenser on concrete supports.

above cuts, produced from 1 pound of crude, where the following constants are used, would be as follows:

Constants

Specific heat of water	=	1.00 B.t.u.
Latent heat of water	=	966.00 B.t.u.
Specific heat of steam	=	0.50 B.t.u.
Mean specific heat of oil	=	0.45 B.t.u.
Mean latent heat of distillate	=	125.00 B.t.u.

Computation

	Pounds B.t.u.		B.t.u.
Condense .0195 pound of distillate vapor..	0.0195×125	=	2.44
Cool .0195 pound of distillate (150° to 70° F.)	.0195× .45×(150° to 70° F.)	=	.70
Condense .0251 pound of distillate vapor..	.0251×125	=	3.14
Cool .0251 pound of distillate (200° to 70° F.)	.0251× .45×(200° to 70° F.)	=	1.47
Condense .0525 pound of distillate vapor..	.0525×125	=	6.56
Cool .0525 pound of distillate (250° to 70° F.)	.0525× .45×(250° to 70° F.)	=	4.25
Condense .0449 pound of distillate vapor..	.0449×125	=	5.61
Cool .0449 pound of distillate (300° to 70° F.)	.0449× .45×(300° to 70° F.)	=	4.65
Condense .0668 pound of distillate vapor [1]	.0668×125	=	8.35
Cool .0668 pound of distillate (350° to 75° F.)	.0668× .45×(350° to 75° F.)	=	8.27

[1] Steam is introduced immediately after fourth cut in proportion of 10 per cent by weight of the overhead distillate down to eighth and ninth cuts, where the percentage is increased to 15 per cent.

	Pounds B.t.u.	B.t.u.
Cool .0067 pound of steam (350° to 212° F.)	.0067× .5 ×(350° to 212° F.) =	.46
Condense .0067 pound of steam	.0067×966 =	6.47
Cool .0067 pound of water (212° to 75° F.)	.0067× 1.00×(212° to 75° F.) =	.92
Condense .0796 pound of distillate vapor	.0796×125 =	9.95
Cool .0796 pound of distillate (400° to 75° F.)	.0796× .45×(400° to 75° F.) =	11.65
Cool .0080 pound of steam (400° to 212° F.)	.0080× .5 ×(400° to 212° F.) =	0.73
Condense .0080 pound of steam	.0080×966 =	7.73
Cool .0080 pound of water (212° to 75° F.)	.0080× 1.00×(212° to 75° F.) =	1.10
Condense .0949 pound of distillate vapor	.0949×125 =	11.86
Cool .0949 pound of distillate (450° to 80° F.)	.0949× .45×(450° to 80° F.) =	15.80
Cool .0095 pound of steam (450° to 212° F.)	.0095× .5 ×(450° to 212° F.) =	1.13
Condense .0095 pound of steam	.0095×966 =	9.18
Cool .0095 pound of water (450° to 80° F.)	.0095× 1. ×(212° to 80° F.) =	1.30
Condense .0509 pound of distillate vapor	.0509×125 =	6.36
Cool .0509 pound of distillate (500° to 80° F.)	.0509× .45×(500° to 80° F.) =	9.62
Cool .0076 pound of steam (500° to 212° F.)	.0076× .5 ×(500° to 212° F.) =	1.09
Condense .0076 pound of steam	.0076×966 =	7.34
Cool .0076 pound of water (500° to 80° F.)	.0076× 1.00×(212° to 80° F.) =	1.04
Condense .0708 pound of distillate	.0708×125 =	8.85
Cool .0708 pound of distillate (550° to 80° F.)	.0708× .45×(550° to 80° F.) =	14.97
Cool .0106 pound of steam (550° to 212° F.)	.0106× .5×(550° to 212° F.) =	1.79
Condense .0106 pound of steam	.0106×966 =	10.24
Cool .0106 pound of water (550° to 80° F.)	.0106× 1.00×(212° to 75° F.) =	1.45
Total heat to be removed from distillate		186.47

One barrel of distillate (plus water) weighs 277.1[1] pounds; therefore the total amount of heat which must be removed per barrel, of crude run, with no allowance for radiation, would be:

$$\frac{186.47 \times 277.1}{.505 \text{ (dist.)} + .0424 \text{ (water)}} = 94{,}391.3 \text{ B.t.u.}$$

Assume a condenser to be required for a 600-barrel discontinuous crude still, stripping as per fractionation record in fifteen hours' running time, where a moderate supply of 60° F. water is available, and where on account of using water over again for other purposes, it is not desired that the condenser overflow exceed 125° F. The amount of heat to be removed under such conditions per hour would be:

$$\frac{94391.3}{15} \times 600 \times .559 \text{ (vol. per cent dist.)} = 2{,}110{,}589 \text{ B.t.u. per hour.}$$

[1] This may be computed from the average proportionate specific gravity of total overhead fractions including water: i.e., 0.792.

From the above results the amount of water necessary for condensation, and the requisite cooling surface may be readily computed as follows:

Where T = temperature vapor entering condenser (395° F.);[1]
T_1 = temperature distillate leaving condenser (75° F.);[2]
t = temperature water leaving condenser (125° F.);
t_1 = temperature water entering condenser (60° F.).

Since 2,110,589 B.t.u. must be absorbed per hour to effect the condensation to the average temperature desired, i.e., 75° F., and as each pound of water will be raised 65° (125−60), absorbing 65 B.t.u., then the water required per hour would be:

$$\frac{2{,}110{,}589}{65\times 1\ (\text{Sp. Heat})} = 32{,}470.6 \text{ pounds.}$$

$$\frac{32{,}470.6}{8.33\times 22.36\ (\text{bbls. dist. per hr.})\times 42} = 4.1 \text{ gals. of water per gal. dist.}$$

Assuming that on account of the high sulphur content of the vapors, cast-iron pipe is to be adopted for a worm, a comparatively low rate of heat exchange should be attempted to secure efficient results, i.e., 25 B.t.u. per square foot per degree of mean temperature difference. With this figure and the preceding data, the necessary condensation surface may be computed as follows:

where θ_a = temperature difference between vapor entering condenser and outgoing water;
θ_e = temperature difference between condensed distillate and entering condensing water.

The mean temperature difference between the two liquids can then be expressed by the formula:

$$\theta_m = \frac{\theta_a - \theta_e}{\log_e \dfrac{\theta_a}{\theta_e}}.*$$

Substituting, we have

$$\theta_m = \frac{(395-125)-(75-60)}{\log_e \dfrac{395-125}{75-60}} = \frac{255}{\log_e \dfrac{270}{15}} = 88.2.$$

The actual amount of condensing surface can now be computed from a variation of the formula:

$$K = \frac{F_W S (T - T_1)}{H\theta_m}.\dagger$$

Or

$$H = \frac{F_W S (T - T_1)}{K\theta_m}$$

[1] This may be computed from proportionate averaging of distillation temperatures in fractionation record.

[2] This may be computed from proportionate averaging of condensation temperatures in fractionation record, or a value arbitrarily adopted.

* Grashof, Franz: Theoretische Maschinenlehre, Bd. 1.

† Hausbrand, E.: Evaporating, condensing and cooling apparatus, 1916.

where H = total cooling surface in square feet;
K = B.t.u. per hour per square foot per degree mean temperature difference = 25°;
θ_m = mean temperature difference = 88.2°;
F_W = weight of distillate passing per hour;
T = temperature vapor entering condenser = 395°;
T_1 = temperature distillate leaving condenser = 75°;
S = proportionate specific and latent heat value.

Then

$$K = \frac{2{,}110{,}589}{25 \times 88.2} = 957.1 \text{ square feet.}$$

$$\frac{957.1}{22.36 \times 42} = 1.2 \text{ square feet per gallon distilled per hour.}$$

In actual practice, on account of the deposition of scale or fouling by mud or organic slime, it is generally customary, especially in designing the condensing worm for vapors of comparatively low temperature, to increase the values obtained by 10 per cent; thus:

Condensing water = 4.5 gallons per gallon of distillate.
Condensing surface = 1.3 square feet per gallon of distillate per hour.

According to I. I. Redwood,[1] the internal area of the cross-section of the worm at the inlet to the condenser should be 0.05 square inch per gallon of distillate per hour and applying this formula to the above problem we have

$$\sqrt{\frac{0.05 \times (957.1 + 95.7)}{0.7854}} = 8.19\text{-inches internal diameter.}$$

Therefore, 8-inch pipe would be selected for the top courses of a worm, which may be conveniently decreased to 6-inch and 4-inch in the amount corresponding to thirds of the condensing surface. Considering the mean surface area in square inch per linear foot of 8-inch, 6-inch and 4-inch cast-iron pipe to be 2.23, 1.67, and 1.13 respectively, the linear feet required of the above sizes of pipe would be as follows:

$$\text{Linear feet 8-inch pipe} = \frac{1052.8}{3 \times 2.23} = 157 \text{ feet} = 13 \text{ 12-foot joints.}$$ [2]

$$\text{Linear feet 6-inch pipe} = \frac{1052.8}{3 \times 1.67} = 210 \text{ feet} = 17 \text{ 12-foot joints.}$$

$$\text{Linear feet 4-inch pipe} = \frac{1052.8}{3 \times 1.13} = 311 \text{ feet} = 26 \text{ 12-foot joints.}$$

If a minimum quantity of water is available the value K should be decreased 50 per cent. Solving the equation previously given, the condensing surface would then be obviously doubled or 2.6 square feet per gallon distillate per hour would be required. Adopting this value and proceeding as above a worm would be computed requiring 10-inch pipe for the upper courses with 8-inch, 6-inch and 4-inch for the succeeding tiers. The total would be as follows:

16 joints of 10-inch pipe.
18 joints of 8-inch pipe.
26 joints of 6-inch pipe.
39 joints of 4-inch pipe.

[1] A Practical Treatise on Mineral Oils and their By-products, pp. 199, 201.
[2] The standard length for cast-iron flanged pipe units is 12 feet.

Such a worm could be conveniently made up in a box 42 feet long by 11 feet wide by 11 feet 6 inches deep, the top plan of a somewhat similarly constructed worm (light worm) being shown in a box of similar dimensions in Fig. 66, while Fig. 67

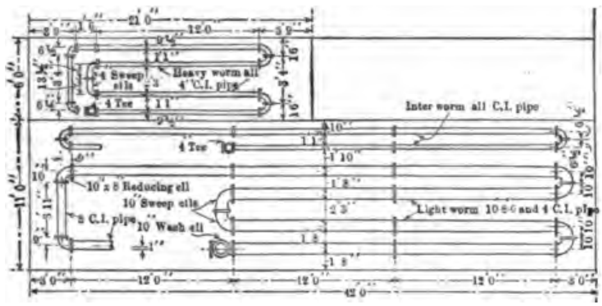


FIG. 66.—Top plan of a continuous cast-iron worm for a 1000-barrel tower shell.

illustrates a type of manifold worm used in steam still and lubrication service, where the ratio of steam to distillate runs high. The complete specifications are appended for a continuous worm condensing coil for a successfully operated 600-barrel

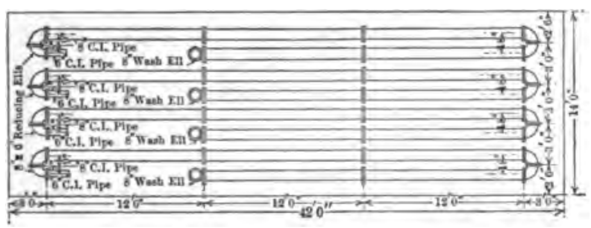


FIG. 67.—Top plan 4-branch C. I. manifold for 1500-barrel steam still.

still performing a similar service to that in the problem under consideration. In these it will be noted that the condensation area and the sizes of the various units which comprise its construction are intermediate between the values computed for moderate and minimum water supplies.

Specifications for a Cast-iron Pipe Worm for a 600-Barrel Crude Still of the Continuous Type

Standard Cast-iron Flanged Pipe and Fittings

Where A = inside diameter of fittings and pipe;
B = distance between center of flange and face of fitting;
C = thickness of fitting or pipe;
D = diameter of flange;
E = thickness of flange;
F = distance between center of flange and face of sweep fittings;
G = length bolts;
H = diameter bolts;
L = length pipe.

Condenser Coil Data—For Vapors from Crude Oil Still—Light Naphtha Distillate

Temperature condensing water entering	Temperature condensing water leaving	Average temperature distillate vapor	Temperature distillate leaving condenser	Mean Temp. difference between distillate and water	Heat extracted from each pound of light naphtha	Low Condensing Rate: Gallons per hour light naphtha condensed per square foot Vento	Low Condensing Rate: B.t.u. per hour per square foot Vento	Low Condensing Rate: Gallons condensing water per hour per square foot Vento	Low Condensing Rate: Square feet per gallon light naphtha per hour Vento
Degrees F.	Degrees F.	Degrees F.	Degrees F.	Deg. F.	B.t.u.				
	80		60	70.1	223	0.596	1476	4.45	1.68
40	100	250	70	74.5	218	0.634	1545	3.10	1.58
	120		80	76.3	213	0.649	1557	2.34	1.54
	80		60	63.9	223	0.543	1345	4.63	1.84
45	100	250	70	69.8	218	0.594	1448	3.17	1.68
	120		80	72.4	213	0.616	1477	2.36	1.63
	80		60	56.5	223	0.480	1189	4.78	2 08
50	100	250	70	64.5	218	0.548	1336	3.22	1.82
	120		80	68.2	213	0.580	1391	2.39	1.72
	100		65	51.7	220	0.439	1077	2.88	2.28
55	120	250	75	58.8	215	0.500	1207	2.24	2.00
	140		85	61.5	210	0.523	1243	1.76	1.91
	100		70	51.7	218	0.439	1069	3.22	2.28
60	120	250	80	58.8	213	0.500	1199	2.41	2.00
	140		90	61.5	208	0.523	1234	1.86	1.91
	100		75	51.7	215	0.439	1060	3.65	2.28
65	120	250	85	58.8	210	0.500	1187	2.60	2.00
	140		95	61.5	205	0.523	1222	1.96	1.91
	100		80	51.7	213	0.439	1052	4.23	2.28
70	120	250	90	58.8	208	0.500	1179	2.84	2.00
	140		100	61.5	203	0.523	1213	2.08	1.91
	100		90	58.7	208	0.499	1177	5.67	2.00
75	120	250	95	58.8	205	0.500	1167	3.12	2.00
	140		100	57.4	203	0.488	1131	2.10	2.05
	100		95	58.7	205	0.499	1165	7.02	2.00
80	120	250	100	58.8	203	0.500	1159	3.49	2.00
	140		105	57.4	200	0.488	1119	2.25	2.05
	100		95	51.7	205	0.439	1025	8.24	2.28
85	120	250	100	53.3	203	0.453	1050	3.62	2.21
	140		105	52.8	200	0.449	1030	2.26	2.23
	100		100	51.7	203	0.439	1017	12.25	2.28
90	120	250	105	53.3	200	0.453	1039	4.17	2.21
	140		110	52.8	198	0.449	1023	2.47	2.23

Using Both Fire and Steam—One Pound of Steam per Gallon of Light Naphtha

Medium Condensing Rate				High Condensing Rate			
Gallons per hour light naphtha condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon light naphtha per hour Vento	Gallons per hour light naphtha condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon light naphtha per hour Vento
0.894	2204	6.67	1.12	1.192	2952	8.90	0.84
0.951	2317	4.60	1.05	1.268	3090	6.20	0.79
0.973	2335	3.51	1.03	1.298	3114	4.68	0.77
0.814	2017	6.94	1.23	1.086	2690	9.26	0.92
0.891	2172	4.75	1.12	1.188	2896	6.34	0.84
0.924	2215	3.54	1.08	1.232	2954	4.72	0.81
0.720	1783	7.17	1.39	0.960	2378	9.56	1.04
0.822	2004	4.83	1.22	1.096	2672	6.44	0.91
0.870	2086	3.58	1.15	1.160	2782	4.78	0.86
0.658	1615	4.32	1.52	0.878	2154	5.76	1.14
0.750	1810	3.36	1.33	1.000	2414	4.48	1.00
0.784	1864	2.64	1.28	1.046	2486	3.52	0.96
0.658	1603	4.83	1.52	0.878	2138	6.44	1.14
0.750	1798	3.61	1.33	1.000	2398	4.82	1.00
0.784	1851	2.79	1.28	1.046	2468	3 72	0.96
0.658	1590	5.47	1.52	0.878	2120	7.30	1.14
0.750	1780	3.90	1.33	1.000	2374	5.20	1.00
0.784	1833	2.94	1.28	1.046	2444	3.92	0.96
0.658	1578	6.34	1.52	0.878	2104	8.46	1.14
0.750	1768	4.26	1.33	1.000	2358	5.68	1.00
0.784	1819	3.12	1.28	1.046	2426	4.16	0.96
0.748	1765	8.50	1.34	0.998	2354	11.34	1.00
0.750	1750	4.68	1.33	1.000	2334	6.24	1.00
0.732	1696	3.15	1.37	0.976	2262	4.20	1.02
0.748	1747	10.53	1.34	0.998	2330	14.04	1.00
0.750	1738	5.23	1.33	1.000	2318	6.98	1.00
0 732	1678	3.37	1.37	0.976	2238	4.50	1.02
0.658	1537	12.36	1.52	0.878	2050	16.48	1.14
0.679	1575	5.43	1.47	0.906	2100	7.24	1.10
0.673	1545	3.39	1.49	0.898	2060	4.52	1.11
0.658	1525	18.37	1.52	0.878	2034	24.50	1.14
0.679	1558	6.25	1.47	0.906	2078	8.34	1.10
0.673	1534	3.70	1.49	0.898	2046	4.94	1.11

Condenser Coil Data—For Vapors from Crude Oil Still—Heavy Naphtha Distillate

Temperature condensing water entering	Temperature condensing water leaving	Average temperature distillate vapor	Temperature distillate leaving condenser	Mean Temp. difference between distillate and water	Heat extracted from each pound of heavy naphtha	Low Condensing Rate			
						Gallons per hour heavy naphtha condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon heavy naphtha per hour Vento
Degrees F.	Degrees F.	Degrees F.	Degrees F.	Deg. F.	B.t.u.				
	80		60	78.2	235	0.581	1880	5.66	1.72
40	100	280	70	83.7	230	0.622	1983	3.98	1.61
	120		80	86.5	225	0.642	2018	3.04	1.56
	80		60	71.4	235	0.530	1715	5.90	1.89
45	100	280	70	78.4	230	0.582	1855	4.06	1.72
	120		80	82.2	225	0.610	1917	3.08	1.64
	80		60	63.3	235	0.460	1488	5.98	2.17
50	100	280	70	72.8	230	0.540	1722	4.15	1.85
	120		80	77.6	225	0.576	1810	3.12	1.74
	100		65	58.8	232	0.437	1402	3.75	2.29
55	120	280	75	67.3	227	0.500	1581	2.93	2.00
	140		85	71.3	222	0.530	1651	2.34	1.89
	100		70	58.8	230	0.437	1393	4.20	2.29
60	120	280	80	67.3	225	0.500	1571	3.16	2.00
	140		90	71.3	220	0.530	1640	2.47	1.89
	100		75	58.8	227	0.437	1382	4.76	2.29
65	120	280	85	67.3	222	0.500	1557	3.41	2.00
	140		95	71.3	217	0.530	1625	2.61	1.89
	100		80	58.8	225	0.437	1373	5.52	2.29
70	120	280	90	67.3	220	0.500	1547	3.73	2.00
	140		100	71.3	215	0.530	1615	2.78	1.89
	100		90	66.3	220	0.492	1523	7.34	2.03
75	120	280	95	67.3	217	0.500	1534	4.11	2.00
	140		100	66.6	215	0.495	1508	2.80	2.02
	100		95	66.3	217	0.492	1510	9.10	2.03
80	120	280	100	67.3	215	0.500	1524	4.59	2.00
	140		105	66.6	212	0.495	1495	3.00	2.02
	100		95	58.8	217	0.437	1340	10.77	2.29
85	120	280	100	61.2	215	0.454	1383	4.76	2.20
	140		105	61.7	212	0.458	1384	3.03	2.18
	100		100	58.8	215	0.437	1332	16.05	2.29
90	120	280	105	61.2	212	0.454	1372	5.51	2.20
	140		110	61.7	210	0.458	1374	3.31	2.18

Using Both Fire and Steam—1½ Pounds of Steam per Gallon Heavy Naphtha

Medium Condensing Rate				High Condensing Rate			
Gallons per hour heavy naphtha condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon heavy naphtha per hour Vento	Gallons per hour heavy naphtha condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon heavy naphtha per hour Vento
0.871	2820	8.49	1.15	1.162	3760	11.32	0.86
0.933	2974	5.97	1.07	1.244	3966	7.96	0.81
0.963	3027	4.56	1.04	1.284	4036	6.08	0.78
0.795	2572	8.85	1.26	1.060	3430	11.80	0.94
0.873	2782	6.09	1.15	1.164	3710	8.12	0.86
0.915	2875	4.62	1.09	1.220	3834	6.16	0.82
0.690	2232	8.97	1.45	0.920	2976	11.96	1.09
0.810	2583	6.22	1.24	1.080	3444	8.30	0.93
0.863	2715	4.68	1.16	1.152	3620	6.24	0.87
0.655	2103	5.62	1.53	0.874	2804	7.50	1.14
0.750	2371	4.39	1.33	1.000	3162	5.86	1.00
0.795	2476	3.51	1.26	1.060	3302	4.68	0.94
0.655	2089	6.30	1.53	0.874	2786	8.40	1.14
0.750	2356	4.74	1.33	1.000	3142	6.32	1.00
0.795	2460	3.70	1.26	1.060	3280	4.94	0.94
0.655	2073	7.14	1.53	0.874	2764	9.52	1.14
0.750	2335	5.11	1.33	1.000	3114	6.82	1.00
0.795	2437	3.91	1.26	1.060	3250	5.22	0.94
0.655	2059	8.28	1.53	0.874	2746	11.04	1.14
0.750	2320	5.59	1.33	1.000	3094	7.46	1.00
0.795	2422	4.17	1.26	1.060	3230	5.56	0.94
0.738	2284	11.01	1.36	0.984	3046	14.68	1.02
0.750	2301	6.16	1.33	1.000	3068	8.22	1.00
0.743	2262	4.20	1.35	0.990	3016	5.60	1.01
0.738	2265	13.65	1.36	0.984	3020	18.20	1.02
0.750	2286	6.88	1.33	1.000	3048	9.18	1.00
0.743	2242	4.50	1.35	0.990	2990	6.00	1.01
0.655	2010	16.15	1.53	0.874	2680	21.54	1.14
0.681	2074	7.14	1.47	0.908	2766	9.52	1.10
0.687	2076	4.54	1.45	0.916	2768	6.06	1.09
0.655	1998	24.07	1.53	0.874	2664	32.10	1.14
0.681	2058	8.26	1.47	0.908	2744	11.02	1.10
0.687	2061	4.96	1.45	0.916	2748	6.62	1.09

Condenser Coil Data—For Vapors from Crude Oil Still—Kerosene or Water-White

Temperature condensing water entering	Temperature condensing water leaving	Average temperature distillate vapor	Temperature distillate leaving condenser	Mean Temp. difference between distillate and water	Heat extracted from each pound of Kerosene	Low Condensing Rate: Gallons per hour of kerosene condensed per square foot Vento	Low Condensing Rate: B.t.u. per hour per square foot Vento	Low Condensing Rate: Gallons condensing water per hour per square foot Vento	Low Condensing Rate: Square feet per gallon of kerosene per hour Vento
Degrees F.	Degrees F.	Degrees F.	Degrees F.	Deg. F.	B.t.u.				
	120		90	139.5	285	0.279	2203	3.32	3.58
40	140	420	100	142.6	280	0.285	2227	2.68	3.51
	160		110	144.8	275	0.290	2241	2.25	3.45
	120		90	134.5	285	0.269	2124	3.41	3.72
45	140	420	100	138.2	280	0.276	2156	2.73	3.62
	160		110	140.6	275	0.281	2172	2.28	3.55
	120		90	129.0	285	0.258	2037	3.51	3.87
50	140	420	100	133.4	280	0.267	2086	2.79	3.74
	160		110	136.3	275	0.273	2110	2.31	3.66
	120		95	129.0	282	0.258	2026	3.76	3.87
55	140	420	105	133.4	277	0.267	2074	2.94	3.74
	160		115	136.3	272	0.273	2098	2.41	3.66
	120		95	123.3	282	0.247	1940	3.90	4.05
60	140	420	105	128.6	277	0.257	1996	3.01	3.89
	160		115	132.0	272	0.264	2029	2.44	3.79
	120		100	123.3	280	0.247	1930	4.28	4.05
65	140	420	110	128.6	275	0.257	1986	3.19	3.89
	160		120	132.0	270	0.264	2018	2.56	3.79
	120		100	117.2	280	0.234	1828	4.40	4.27
70	140	420	110	123.3	275	0.247	1908	3.28	4.05
	160		120	127.4	270	0.255	1949	2.61	3.92
	120		105	117.2	277	0.234	1818	4.87	4.27
75	140	420	115	123.3	272	0.247	1898	3.52	4.05
	160		125	127.4	267	0.255	1938	2.75	3.92
	120		105	110.7	277	0.221	1717	5.17	4.52
80	140	420	115	117.9	272	0.236	1813	3.64	4.24
	160		125	122.6	267	0.245	1862	2.80	4.08
	120		110	110.7	275	0.221	1707	5.88	4.52
85	140	420	120	117.9	270	0.236	1804	3.95	4.24
	160		130	122.6	265	0.245	1853	2.98	4.08
	120		110	103.4	275	0.207	1600	6.42	4.83
90	140	420	120	112.0	270	0.224	1712	4.13	4.47
	160		130	117.5	265	0.235	1777	3.06	4.25

Distillate Using Both Fire and Steam—Five Pounds of Steam per Gallon Kerosene

Medium Condensing Rate				High Condensing Rate			
Gallons per hour of kerosene condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon of kerosene per hour Vento	Gallons per hour of kerosene condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon of kerosene per hour Vento
0.418	3304	4.98	2.39	0.558	4406	6.64	1.79
0.428	3340	4.02	2.34	0.570	4454	5.36	1.75
0.435	3361	3.37	2.30	0.580	4482	4.50	1.73
0.403	3186	5.11	2.48	0.538	4248	6.82	1.86
0.414	3234	4.09	2.42	0.552	4312	5.46	1.81
0.421	3258	3.42	2.38	0.562	4354	4.56	1.78
0.387	3055	5.26	2.59	0.516	4074	7.02	1.94
0.400	3129	4.18	2.50	0.533	4172	5.58	1.88
0.409	3165	3.46	2.44	0.546	4220	4.62	1.83
0.387	3039	5.64	2.59	0.516	4052	7.52	1.94
0.400	3111	4.41	2.50	0.533	4148	5.88	1.88
0.409	3147	3.61	2.44	0.546	4196	4.82	1.83
0.370	2910	5.85	2.70	0.494	3880	7.80	2.03
0.386	2994	4.51	2.59	0.514	3992	6.02	1.95
0.396	3043	3.66	2.53	0.528	4058	4.88	1.90
0.370	2895	6.42	2.70	0.494	3860	8.56	2.03
0.386	2979	4.78	2.59	0.514	3972	6.38	1.95
0.396	3027	3.84	2.53	0.528	4036	5.12	1.90
0.351	2742	6.60	2.85	0.468	3656	8.80	2.14
0.370	2862	4.92	2.71	0.494	3816	6.56	2.03
0.382	2923	3.91	2.62	0.510	3898	5.22	1.96
0.351	2727	7.30	2.85	0.468	3636	9.74	2.14
0.370	2847	5.28	2.71	0.494	3796	7.04	2.03
0.382	2907	4.12	2.62	0.510	3876	5.50	1.96
0.331	2575	7.75	3.02	0.442	3434	10.34	2.27
0.354	2719	5.46	2.82	0.472	3626	7.28	2.12
0.367	2793	4.20	2.73	0.490	3724	5.60	2.04
0.331	2560	8.82	3.02	0.442	3414	11.76	2.27
0.354	2706	5.92	2.82	0.472	3608	7.90	2.12
0.367	2779	4.47	2.73	0.490	3706	5.96	2.04
0.310	2400	9.63	3.23	0.414	3200	12.84	2.42
0.336	2568	6.19	2.98	0.448	3424	8.26	2.23
0.352	2665	4.59	2.84	0.470	3554	6.12	2.13

Condenser Coil Data—For Vapors from Crude Oil Still—Wax Distillate—or Fuel Gallon Wax

Temperature condensing water entering	Temperature condensing water leaving	Average temperature distillate vapor	Temperature distillate leaving condenser	Mean Temp. difference between distillate and water	Heat extracted from each pound of wax oils	Low Condensing Rate: Gallons per hour wax oils condensed per square foot Vento	Low Condensing Rate: B.t.u. per hour per square foot Vento	Low Condensing Rate: Gallons condensing water per hour per square foot Vento	Low Condensing Rate: Square feet per gallon wax oils per hour Vento
Degrees F.	Degrees F.	Degrees F.	Degrees F.	Deg. F.	B.t.u.				
	170		120	208.0	350	0.336	14,680	13.62	2.98
40	190	600	140	219.4	340	0.354	15,220	12.22	2.83
	210		160	229.0	330	0.369	15,590	11.04	2.71
	170		120	203.3	350	0.328	14,340	13.83	3.05
45	190	600	140	215.2	340	0.347	14,910	12.39	2.88
	210		160	225.0	330	0.363	15,330	11.20;	2.75
	170		120	198.3	350	0.320	13,980	14.03	3.12
50	190	600	140	211.0	340	0.340	14,610	12.57	2.94
	210		160	221.0	330	0.356	15,040	11.32	2.81
	170		120	193.2	350	0.312	13,640	14.30	3.21
55	190	600	140	206.5	340	0.333	14,310	12.77	3.00
	210		160	217.3	330	0.350	14,780	11.48	2.86
	170		120	187.8	350	0.303	13,240	14.50	3.30
60	190	600	140	202.0	340	0.326	14,010	13.00	3.07
	210		160	212.9	330	0.343	14,490	11.63	2.91
	170		120	182.3	350	0.294	12,850	14.74	3.40
65	190	600	140	197.1	340	0.318	13,670	13.18	3.15
	210		160	209.0	330	0.337	14,230	11.82	2.97
	170		120	176.6	350	0.285	12,460	15.01	3.51
70	190	600	140	192.3	340	0.310	13,320	13.37	3.23
	210		160	204.9	330	0.330	13,940	12.00	3.03
	170		120	170.5	350	0.275	12,020	15.24	3.64
75	190	600	140	187.2	340	0.302	12,980	13.60	3.31
	210		160	200.0	330	0.322	13,600	12.14	3.11
	170		120	164.1	350	0.265	11,580	15.51	3.77
80	190	600	140	182.0	340	0.293	12,590	13.79	3.41
	210		160	195.5	330	0.315	13,310	12.34	3.17
	170		120	157.3	350	0.254	11,100	15.73	3.94
85	190	600	140	176.6	340	0.285	12,240	14.05	3.51
	210		160	191.2	330	0.308	13,020	12.56	3.25
	170		120	150.4	350	0.243	10,620	16.00	4.12
90	190	600	140	170.8	340	0.275	11,820	14.24	3.64
	210		160	186.4	330	0.300	12,680	12.73	3.33

Oil—or Lubricating Oil, Using Both Fire and Steam—33 Pounds of Steam per Distillate

Medium Condensing Rate				High Condensing Rate			
Gallons per hour wax oils condensed per square foot VENTO	B.t.u. per hour per square foot VENTO	Gallons condensing water per hour per square foot VENTO	Square feet per gallon wax oils per hour VENTO	Gallons per hour wax oils condensed per square foot VENTO	B.t.u. per hour per square foot VENTO	Gallons condensing water per hour per square foot VENTO	Square feet per gallon wax oils per hour VENTO
0.504	22,020	20.43	1.98	0.672	29,360	27.24	1.49
0.531	22,830	18.33	1.88	0.708	30,440	24.44	1.41
0.553	23,385	16.56	1.81	0.738	31,180	22.08	1.35
0.492	21,510	20.74	2.03	0.656	28,680	27.66	1.53
0.520	22,365	18.58	1.92	0.694	29,820	24.78	1.44
0.545	22,995	16.80	1.84	0.726	30,660	22.40	1.38
0.480	20,970	21.04	2.08	0.640	27,960	28.06	1.56
0.510	21,915	18.85	1.96	0.680	29,220	25.14	1.47
0.534	22,560	16.98	1.87	0.712	30,080	22.64	1.40
0.468	20,460	21.45	2.14	0.624	27,280	28.60	1.60
0.500	21,465	19.15	2.00	0.667	28,620	25.54	1.50
0.525	22,170	17.22	1.91	0.700	29,560	22.96	1.43
0.455	19,860	21.75	2.20	0.606	26,480	29.00	1.65
0.489	21,015	19.50	2.04	0.652	28,020	26.00	1.53
0.515	21,735	17.44	1.94	0.686	28,980	23.26	1.46
0.441	19,275	22.11	2.27	0.588	25,700	29.48	1.70
0.477	20,505	19.77	2.10	0.636	27,340	26.36	1.57
0.505	21,345	17.73	1.98	0.674	28,460	23.64	1.48
0.428	18,690	22.51	2.34	0.570	24,920	30.02	1.75
0.465	19,980	20.05	2.15	0.620	26,640	26.74	1.61
0.495	20,910	18.00	2.02	0.660	27,880	24.00	1.52
0.412	18,030	22.86	2.43	0.550	24,040	30.48	1.82
0.453	19,470	20.40	2.21	0.604	25,960	27.20	1.66
0.483	20,400	18.21	2.07	0.644	27,200	24.28	1.55
0.398	17,370	23.26	2.51	0.530	23,160	31.02	1.89
0.440	18,885	20.68	2.28	0.586	25,180	27.58	1.71
0.472	19,965	18.51	2.12	0.630	26,620	24.68	1.59
0.381	16,650	23.59	2.63	0.508	22,200	31.46	1.97
0.428	18,360	21.07	2.34	0.570	24,480	28.10	1.75
0.462	19,530	18.84	2.17	0.616	26,040	25.12	1.62
0.365	15,930	24.00	2.74	0.486	21,240	32.00	2.06
0.413	17,730	21.36	2.42	0.550	23,640	28 48	1.82
0.450	19,020	19.09	2.22	0.600	25,360	25.46	1.67

Condenser Coil Data—For Rerun of Crude Benzine from Steam Still—No Fire Used—20 Per Cent, 8.5 Pounds

Temperature condensing water entering	Temperature condensing water leaving	Average temperature distillate vapor	Temperature distillate leaving condenser	Mean Temp. difference between distillate and water	Heat extracted from each pound of gasoline	3½ Pounds Steam	
						Gallons per hour of gasoline condensed per square foot Vento	B.t.u. per hour per square foot Vento
Degrees F.	Degrees F.	Degrees F.	Degrees F.	Deg. F.	B.t.u.		
	120		60	47.2	211	0.845	4433
40	140	212	70	48.0	206	0.860	4455
	160		80	45.7	201	0.819	4190
	120		60	42.5	211	0.761	3992
45	140	212	70	44.4	206	0.795	4120
	160		80	43.0	201	0.770	3938
	120		60	37.0	211	0.663	3478
50	140	212	70	40.6	206	0.727	3767
	160		80	40.1	201	0.718	3672
	120		65	37.0	208	0.663	3455
55	140	212	70	36.3	206	0.650	3368
	160		75	33.5	203	0.600	3086
	120		70	37.0	206	0.663	3435
60	140	212	80	40.6	201	0.727	3718
	160		90	40.1	196	0.718	3623
	120		75	37.0	203	0.663	3410
65	140	212	85	40.6	198	0.727	3691
	160		95	40.1	193	0.718	3600
	120		80	37.0	201	0.663	3390
70	140	212	90	40.6	196	0.727	3670
	160		100	40.1	191	0.718	3578
	120		90	42.5	196	0.761	3840
75	140	212	95	40.6	193	0.727	3644
	160		100	36.9	191	0.661	3294
	120		95	42.5	193	0.761	3815
80	140	212	100	40.6	191	0.727	3621
	160		105	36.9	188	0.661	3270
	120		95	37.0	193	0.663	3324
85	140	212	100	36.3	191	0.650	3240
	160		105	33.5	188	0.600	2968
	120		100	37.0	191	0.663	3304
90	140	212	105	36.3	188	0.650	3213
	160		110	33.5	186	0.600	2948

First 60 Per Cent of Run Averages 3.5 Pounds of Steam per Gallon Gasoline—Next —Next 20 Per Cent, 30 Pounds

PER GALLON		20 POUNDS STEAM PER GALLON			90 POUNDS STEAM PER GALLON		
Gallons condensing water per hour per square foot VENTO	Square feet per gallon of gasoline per hour VENTO	Gallons per hour of gasoline condensed per square foot VENTO	B.t.u. per hour per square foot VENTO	Gallons condensing water per hour per square foot VENTO	Gallons per hour of gasoline condensed per square foot VENTO	B.t.u. per hour per square foot VENTO	Gallons condensing water per hour per square foot VENTO
6.68	1.18	0.0704	1672	2.52	0.0217	2220	3.34
5.37	1.16	0.0717	1687	2.03	0.0221	2241	2.70
4.21	1.22	0.0683	1591	1.60	0.0210	2110	2.12
6.42	1.31	0.0634	1506	1.42	0.0195	1995	3.21
5.23	1.26	0.0662	1557	1.98	0.0204	2069	2.62
4.13	1.30	0.0642	1495	1.57	0.0198	1988	2.08
5.98	1.51	0.0552	1312	2.26	0.0170	1740	2.99
5.04	1.38	0.0606	1426	1.91	0.0187	1897	2.54
4.02	1.39	0.0598	1393	1.53	0.0184	1848	2.02
6.40	1.51	0.0552	1309	2.43	0.0170	1731	3.21
4.77	1.54	0.0542	1275	1.81	0.0167	1693	2.40
3.54	1.67	0.0500	1170	1.34	0.0154	1554	1.78
6.90	1.51	0.0552	1298	2.61	0.0170	1724	3.46
5.60	1.38	0.0606	1412	2.13	0.0187	1878	2.83
4.36	1.39	0.0598	1379	1.66	0.0184	1831	2.21
7.46	1.51	0.0552	1292	2.83	0.0170	1716	3.76
5.94	1.38	0.0606	1404	2.26	0.0187	1869	3.00
4.57	1.39	0.0598	1372	1.74	0.0184	1822	2.31
8.17	1.51	0.0552	1286	3.10	0.0170	1708	4.12
6.32	1.38	0.0606	1398	2.41	0.0187	1861	3.20
4.79	1.39	0.0598	1365	1.83	0.0184	1813	2.43
10.28	1.31	0.0634	1462	3.91	0.0195	1941	5.20
6.76	1.38	0.0606	1390	2.58	0.0187	1852	3.43
4.67	1.51	0.0551	1257	1.78	0.0170	1675	2.37
11.49	1.31	0.0634	1454	4.38	0.0195	1931	5.82
7.28	1.38	0.0606	1383	2.78	0.0187	1843	3.70
4.93	1.51	0.0551	1252	1.89	0.0170	1668	2.51
11.44	1.51	0.0552	1266	4.36	0.0170	1683	5.80
7.10	1.54	0.0542	1237	2.71	0.0167	1646	3.61
4.77	1.67	0.0500	1136	1.83	0.0154	1511	2.43
13.27	1.51	0.0552	1260	5.06	0.0170	1676	6.73
7.74	1.54	0.0542	1231	2.97	0.0167	1638	3.95
5.07	1.67	0.0500	1130	1.94	0.0154	1503	2.59

Condenser Coil Data—For Crude Oil Still

Temperature condensing water entering	Temperature condensing water leaving	Average temperature distillate vapor	Temperature distillate leaving condenser	Mean Temp. difference between distillate and water	Heat extracted from each pound of gasoline	Low Condensing Rate: Gallons per hour of gasoline condensed per square foot Vento	Low Condensing Rate: B.t.u. per hour per square foot Vento	Low Condensing Rate: Gallons condensing water per hour per square foot Vento	Low Condensing Rate: Square feet per gallon of gasoline per hour Vento
Degrees F.	Degrees F.	Degrees F.	Degrees F.	Deg. F.	B.t.u.				
	80		60	89.8	257	0.394	633	1.91	2.54
40	100	325	70	96.8	252	0.424	668	1.34	2.36
	120		80	101.0	247	0.443	684	1.03	2.26
	80		60	82.4	257	0.361	580	2.00	2.77
45	100	325	70	91.0	252	0.399	628	1.38	2.51
	120		80	96.2	247	0.422	652	1.05	2.37
	80		60	73.5	257	0.322	517	2.08	3.10
50	100	325	70	84.7	252	0.371	584	1.41	2.69
	120		80	91.1	247	0.400	618	1.06	2.50
	100		65	69.1	255	0.303	483	1.29	3.30
55	120	325	75	79.8	250	0.350	547	1.01	2.86
	140		85	85.2	245	0.374	573	0.81	2.68
	100		70	69.1	252	0.303	477	1.44	3.30
60	120	325	80	79.8	247	0.350	540	1.08	2.86
	140		90	85.2	242	0.374	566	0.85	2.68
	100		75	69.1	250	0.303	473	1.63	3.30
65	120	325	85	79.8	245	0.350	536	1.17	2.86
	140		95	85.2	240	0.374	561	0.90	2.68
	100		80	69.1	247	0.303	468	1.88	3.30
70	120	325	90	79.8	242	0.350	530	1.28	2.86
	140		100	85.2	237	0.374	554	0.95	2.68
	100		90	77.6	242	0.340	514	2.48	2.94
75	120	325	95	79.8	240	0.350	525	1.41	2.86
	140		100	79.9	237	0.351	530	0.96	2.85
	100		95	77.6	240	0.340	510	3.07	2.94
80	120	325	100	79.8	237	0.350	518	1.56	2.86
	140		105	79.9	235	0.351	516	1.04	2.85
	100		95	69.1	240	0.303	454	3.65	3.30
85	120	325	100	72.6	237	0.318	471	1.62	3.15
	140		105	74.2	235	0.325	477	1.05	3.08
	100		100	69.1	237	0.303	449	5.40	3.30
90	120	325	105	72.6	235	0.318	467	1.88	3.15
	140		110	74.2	232	0.325	471	1.13	3.08

—Using Fire Only—Gasoline Distillate

Medium Condensing Rate				High Condensing Rate			
Gallons per hour of gasoline condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon of gasoline per hour Vento	Gallons per hour of gasoline condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon of gasoline per hour Vento
0.704	1130	3.41	1.42	1.126	1808	5.45	0.89
0.757	1192	2.39	1.32	1.212	1908	3.83	0.83
0.791	1222	1.84	1.26	1.266	1955	2.94	0.79
0.645	1036	3.57	1.55	1.032	1657	5.70	0.98
0.713	1123	2.46	1.40	1.140	1795	3.93	0.88
0.754	1164	1.87	1.33	1.206	1861	2.99	0.83
0.575	924	3.71	1.74	0.920	1477	5.94	1.09
0.663	1044	2.52	1.51	1.060	1670	4.02	0.94
0.714	1102	1.90	1.40	1.143	1765	3.04	0.87
0.541	862	2.31	1.85	0.866	1380	3.70	1.16
0.625	977	1.81	1.60	1.000	1562	2.90	1.00
0.668	1023	1.45	1.50	1.068	1635	2.32	0.94
0.541	852	2.57	1.85	0.866	1364	4.11	1.16
0.625	965	1.94	1.60	1.000	1544	3.10	1.00
0.668	1010	1.52	1.50	1.068	1615	2.43	0.94
0.541	846	2.91	1.85	0.866	1353	4.66	1.16
0.625	957	2.10	1.60	1.000	1531	3.35	1.00
0.668	1002	1.61	1.50	1.068	1603	2.58	0.94
0.541	836	3.36	1.85	0.866	1337	5.37	1.16
0.625	946	2.28	1.60	1.000	1512	3.64	1.00
0.668	990	1.70	1.50	1.068	1582	2.72	0.94
0.607	918	4.42	1.65	0.972	1470	7.08	1.03
0.625	938	2.51	1.60	1.000	1500	4.02	1.00
0.627	929	1.72	1.59	1.003	1486	2.75	1.00
0.607	910	5.48	1.65	0.972	1458	8.78	1.03
0.625	926	2.79	1.60	1.000	1481	4.46	1.00
0.627	921	1.85	1.59	1.003	1475	2.96	1.00
0.541	812	6.52	1.85	0.866	1300	10.44	1.15
0.568	842	2.90	1.76	0.908	1345	4.63	1.10
0.580	852	1.87	1.72	0.928	1363	2.99	1.08
0.541	801	9.65	1.85	0.866	1282	15.45	1.15
0.568	834	3.35	1.76	0.908	1334	5.36	1.10
0.580	841	2.03	1.72	0.928	1346	3.24	1.08

Condenser Coil Data—For Crude Oil Still—

Temperature condensing water entering	Temperature condensing water leaving	Average temperature distillate vapor	Temperature distillate leaving condenser	Mean Temp. difference between distillate and water	Heat extracted from each pound of kerosene	Low Condensing Rate: Gallons per hour of kerosene condensed per square foot Vento	Low Condensing Rate: B.t.u. per hour per square foot Vento	Low Condensing Rate: Gallons condensing water per hour per square foot Vento	Low Condensing Rate: Square feet per gallon of kerosene per hour Vento
Degrees F.	Degrees F.	Degrees F.	Degrees F.	Deg. F.	B.t.u.				
	120		90	162.7	320	0.311	677	1.02	3.21
40	140	500	100	167.5	315	0.320	686	0.83	3.12
	160		110	170.7	310	0.326	687	0.69	3.06
	120		90	157.0	320	0.300	653	1.05	3.33
45	140	500	100	162.2	315	0.310	664	0.84	3.22
	160		110	166.4	310	0.318	670	0.70	3.14
	120		90	150.9	320	0.288	627	1.08	3.48
50	140	500	100	157.0	315	0.300	643	0.86	3.33
	160		110	161.5	310	0.309	651	0.71	3.23
	120		95	150.9	317	0.288	621	1.15	3.48
55	140	500	105	157.0	312	0.300	636	0.90	3.33
	160		115	161.5	307	0.309	645	0.74	3.23
	120		95	144.6	317	0.276	595	1.19	3.62
60	140	500	105	151.6	312	0.290	615	0.93	3.45
	160		115	156.4	307	0.299	624	0.75	3.34
	120		100	144.6	315	0.276	591	1.30	3.62
65	140	500	110	151.6	310	0.290	611	0.98	3.45
	160		120	156.4	305	0.299	620	0.79	3.34
	120		100	137.8	315	0.263	563	1.36	3.80
70	140	500	110	145.7	310	0.278	586	1.01	3.60
	160		120	151.3	305	0.289	600	0.80	3.46
	120		105	137.8	312	0.263	558	1.49	3.80
75	140	500	115	145.7	307	0.278	580	1.07	3.60
	160		125	151.3	302	0.289	594	0.84	3.46
	120		105	130.3	312	0.249	528	1.59	4.02
80	140	500	115	139.3	307	0.266	555	1.12	3.76
	160		125	145.8	302	0.279	573	0.86	3.58
	120		110	130.3	310	0.249	525	1.81	4.02
85	140	500	120	139.3	305	0.266	552	1.21	3.76
	160		130	145.8	300	0.279	569	0.91	3.58
	120		110	122.2	310	0.233	491	1.97	4.29
90	140	500	120	132.8	305	0.254	527	1.27	3.94
	160		130	140.1	300	0.268	546	0.94	3.73

Using Fire Only—Kerosene Distillate

Medium Condensing Rate				High Condensing Rate			
Gallons per hour of kerosene condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon of kerosene per hour Vento	Gallons per hour of kerosene condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon of kerosene per hour Vento
0.518	1127	1.70	1.93	1.037	2256	3.40	0.96
0.534	1143	1.37	1.87	1.067	2284	2.75	0.94
0.544	1146	1.15	1.84	1.087	2292	2.30	0.92
0.500	1088	1.75	2.00	1.000	2176	3.50	1.00
0.517	1108	1.40	1.94	1.034	2217	2.81	0.97
0.530	1117	1.17	1.89	1.060	2235	2.34	0.94
0.480	1044	1.80	2.08	0.960	2089	3.60	1.04
0.500	1071	1.43	2.00	1.000	2142	2.87	1.00
0.517	1090	1.19	1.94	1.030	2172	2.38	0.97
0.480	1034	1.91	2.08	0.960	2069	3.83	1.04
0.500	1061	1.50	2.00	1.000	2122	3.01	1.00
0.517	1079	1.23	1.94	1.030	2150	2.47	0.97
0.460	992	1.99	2.17	0.920	1982	3.98	1.09
0.484	1027	1.54	2.06	0.967	2052	3.09	1.03
0.498	1040	1.25	2.01	0.996	2079	2.50	1.00
0.460	986	2.16	2.17	0.920	1971	4.32	1.09
0.484	1020	1.63	2.06	0.967	2038	3.27	1.03
0.498	1032	1.31	2.01	0.996	2066	2.62	1.00
0.438	938	2.26	2.28	0.876	1876	4.52	1.14
0.464	978	1.68	2.16	0.926	1952	3.36	1.08
0.482	1000	1.33	2.08	0.963	1997	2.67	1.04
0.438	929	2.49	2.28	0.876	1858	4.98	1.14
0.464	968	1.79	2.16	0.926	1932	3.58	1.08
0.482	990	1.40	2.08	0.963	1978	2.80	1.04
0.415	880	2.65	2.41	0.830	1761	5.30	1.20
0.443	924	1.86	2.26	0.886	1850	3.72	1.13
0.465	955	1.44	2.15	0.930	1910	2.88	1.08
0.415	875	3.01	2.41	0.830	1750	6.02	1.20
0.443	919	2.01	2.26	0.886	1837	4.02	1.13
0.465	948	1.52	2.15	0.930	1897	3.05	1.08
0.388	818	3.28	2.58	0.776	1635	6.56	1.29
0.424	879	2.11	2.36	0.846	1755	4.23	1.18
0.447	912	1.57	2.24	0.893	1822	3.14	1.12

Condenser Coil Data—For Crude Oil Still—Using Fire Only—Gas and Fuel

Temperature condensing water entering	Temperature condensing water leaving	Average temperature distillate vapor	Temperature distillate leaving condenser	Mean Temp. difference between distillate and water	Heat extracted from each pound of fuel oil	Low Condensing Rate: Gallons per hour fuel oil condensed per square foot Vento	Low Condensing Rate: B.t.u. per hour per square foot Vento	Low Condensing Rate: Gallons condensing water per hour per square foot Vento	Low Condensing Rate: Square feet per gallon fuel oil per hour Vento
Degrees F.	Degrees F.	Degrees F.	Degrees F.	Deg. F.	B.t.u.				
	170		120	223	375	0.351	948	0.88	2.85
40	190	650	140	236	365	0.372	978	0.79	2.69
	210		160	246	355	0.388	992	0.70	2.58
	170		120	218	375	0.344	928	0.89	2.91
45	190	650	140	231	365	0.364	956	0.79	2.75
	210		160	242	355	0.381	974	0.71	2.63
	170		120	213	375	0.336	907	0.91	2.98
50	190	650	140	227	365	0.358	941	0.81	2.80
	210		160	238	355	0.375	958	0.72	2.67
	170		120	207	375	0.326	880	0.92	3.07
55	190	650	140	222	365	0.350	920	0.82	2.86
	210		160	234	355	0.369	943	0.73	2.71
	170		120	202	375	0.318	858	0.94	3.15
60	190	650	140	217	365	0.342	899	0.83	2.93
	210		160	229	355	0.361	922	0.74	2.77
	170		120	196	375	0.309	834	0.96	3.24
65	190	650	140	212	365	0.334	878	0.85	3.00
	210		160	225	355	0.355	907	0.75	2.82
	170		120	190	375	0.300	810	0.98	3.30
70	190	650	140	207	365	0.326	856	0.86	3.07
	210		160	220	355	0.347	887	0.76	2.88
	170		120	184	375	0.290	783	0.99	3.45
75	190	650	140	202	365	0.318	836	0.87	3.14
	210		160	216	355	0.340	869	0.78	2.94
	170		120	177	375	0.279	753	1.01	3.58
80	190	650	140	196	365	0.309	812	0.89	3.24
	210		160	211	355	0.333	851	0.79	3.00
	170		120	170	375	0.268	723	1.03	3.73
85	190	650	140	191	365	0.301	790	0.91	3.32
	210		160	206	355	0.325	831	0.80	3.08
	170		120	162	375	0.255	688	1.04	3.92
90	190	650	140	185	365	0.292	767	0.92	3.43
	210		160	201	355	0.317	810	0.81	3.15

Oil Stock Producing Gas Oil—Fuel Oil—Solar Oil—Wax Oil—Lubricating Oil

Medium Condensing Rate				High Condensing Rate			
Gallons per hour fuel oil condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon fuel oil per hour Vento	Gallons per hour fuel oil condensed per square foot Vento	B.t.u. per hour per square foot Vento	Gallons condensing water per hour per square foot Vento	Square feet per gallon fuel oil per hour Vento
0.626	1693	1.57	1.60	1.002	2710	2.51	1.00
0.664	1747	1.40	1.51	1.063	2795	2.24	0.94
0.693	1772	1.26	1.44	1.108	2835	2.01	0.90
0.614	1658	1.60	1.63	0.983	2652	2.56	1.02
0.650	1707	1.42	1.54	1.040	2731	2.27	0.96
0.680	1740	1.27	1.47	1.088	2783	2.03	0.92
0.600	1620	1.62	1.67	0.960	2592	2.60	1.04
0.639	1681	1.44	1.57	1.022	2690	2.31	0.98
0.670	1710	1.29	1.49	1.072	2737	2.06	0.93
0.583	1572	1.64	1.71	0.932	2514	2.63	1.07
0.625	1642	1.47	1.60	1.000	2628	2.35	1.00
0.659	1684	1.31	1.52	1.054	2694	2.09	0.95
0.568	1532	1.68	1.76	0.909	2452	2.69	1.10
0.611	1605	1.49	1.64	0.977	2569	2.38	1.02
0.645	1646	1.32	1.55	1.031	2634	2.12	0.97
0.552	1489	1.71	1.81	0.883	2382	2.73	1.13
0.596	1568	1.51	1.68	0.954	2509	2.42	1.05
0.634	1620	1.34	1.58	1.014	2592	2.15	0.99
0.536	1446	1.74	1.87	0.857	2314	2.79	1.17
0.582	1528	1.53	1.72	0.932	2446	2.45	1.07
0.620	1584	1.36	1.61	0.992	2534	2.18	1.01
0.518	1398	1.77	1.93	0.829	2237	2.84	1.21
0.568	1493	1.56	1.76	0.909	2389	2.50	1.10
0.607	1552	1.39	1.65	0.972	2483	2.22	1.03
0.498	1345	1.80	2.00	0.797	2152	2.88	1.25
0.552	1450	1.59	1.81	0.883	2320	2.54	1.13
0.595	1520	1.41	1.68	0.952	2432	2.26	1.05
0.479	1292	1.83	2.09	0.766	2067	2.93	1.31
0.537	1410	1.62	1.86	0.860	2257	2.59	1.16
0.581	1483	1.43	1.72	0.929	2374	2.29	1.08
0.456	1229	1.85	2.19	0.729	1967	2.96	1.37
0.522	1370	1.65	1.92	0.835	2192	2.64	1.20
0.566	1446	1.45	1.77	0.906	2314	2.32	1.10

Specifications for a Cast-iron Pipe Worm for a 600-Barrel Crude Still—Continued.

No. required	Type	A inches	B inches	C inches	D inches	E inches	F inches	No. threads
1	Wash ell......	8	9	.75	13½	1⅛	9	
1	Reducing ell...	8	9	.75	13½	1⅛		
1	Reducing ell...	6	8	.75	11	1		
4	Plain ell.......	8	9	.75	13½	1⅛		
23	Plain ell.......	6	8	.75	11	1		
25	Plain ell.......	4	6½	.63	9	15/16		
2	Sweep ell......	8	9	.75	13½	1⅛	13½	
8	Sweep ell......	6	8	.75	11	1	14½	
8	Sweep ell......	4	6½	.63	9	15/16	16	
1	T's...........	4	6½	.63	9	15/16		
1	Flange........	10	12	2⅜	16	1 3/16		8
3	Flange........	4	5.50	1¾	9	15/16		8

No. required	Type	A ins.	L feet	L ins.	C ins.	D ins.	E ins.	Bolts ins.	Bolt circle ins.	Size ins.	Diameter bolt hole
9	Pipe...	8	12	0	.56	13½	1⅛	8	11¾	¾	⅞
40	Pipe...	6	12	0	.51	11	1	6	9½	¾	⅞
4	Pipe...	6	3	9	.51	11	1	6	9½	¾	⅞
43	Pipe...	4	12	0	.48	9	15/16	4	7½	⅝	¾
4	Pipe...	4	3	9	.48	9	15/16	4	7½	⅝	¾
1	Pipe...	4	1	11	.48	9	15/16	4	7½	⅝	¾

No. required	Type	Nuts	G inches	H inches
150	Bolts	Hex.	3¼	¾
460	Bolts	Hex.	3	¾
10	Bolts	Hex.	3½	⅝
350	Bolts	Hex.	3	⅝

The American Radiator Company has courteously allowed the publication of the preceding condenser coil data which can be generally applied to the design of standard pipe condensers by increasing the values given by 20 per cent as required.

In general, standard worm design should be controlled by; (*a*) type of coil, i.e., whether continuous or manifold; and (*b*) composition. With respect to (*a*) manifold construction is preferably adopted where the ratio of steam per gallon of distillate produced exceeds 10 pounds, although each refiner is apt to have his own views as to the efficiency of continuous and manifold types. The latter is frequently installed where wrought pipe is used on account of a low initial cost, and the easy handling of small

sizes of pipe required, even where a minimum quantity of steam is used in the process. The material used is obviously limited to some form of iron. Steel or wrought-iron pipe, on account of lesser thickness, has a higher rate of heat interchange than cast-iron pipe but both types of wrought pipe rapidly deteriorate from scaling and the action of sulphur-bearing distillates, steel generally more rapidly in exposed layers than iron. Where wrought pipe is installed, it is therefore an excellent plan to use genuine wrought-iron pipe in the upper courses, and steel (line or merchant) pipe in the succeeding tiers, thereby equalizing the life of the coil. Such pipe, however, should never be used in connection with distillates of high sulphur content, and even with cast-iron pipe, provision should be made to rotate the latter through 90° at occasional intervals. Other types of condensers, such as spray, tubular box and drum, upright vertical, and Vento sections are in successful use in many refineries and will be touched upon in the topics devoted to special apparatus.

Condensers for tar stills were formally equipped with many feet of aerial worm of various sizes with intervening vapor drums, in which the heavier lubricating distillates partially condensed and flowed through individual standard coils to the receiving house in separate streams. Such construction has been replaced for the most part by special types of towers, which will be discussed in a later section. The condensates

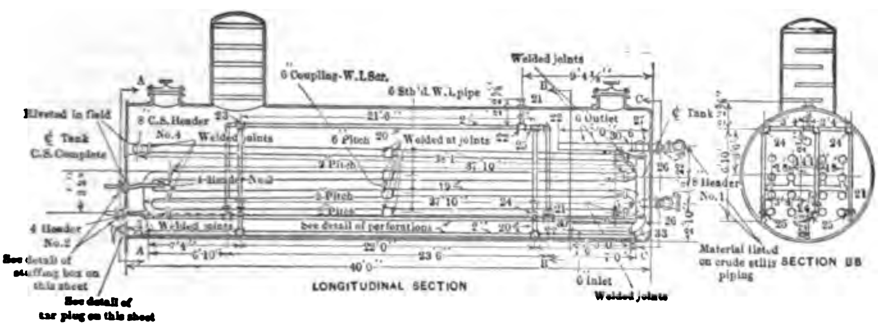


FIG. 68.—Details of a heat exchanger 10 feet in diameter by 40 feet in the shell.

from the latter are cooled by standard worm sections similiar to those for ordinary distillate condensation, except that much less pipe is required, the intention being to allow the heavy lubrication fractions or wax distillate to run warm without danger of congealing. The top plan of such a condenser, including light, intermediate, and heavy worms (the second and last-named being designed for gas-oil and wax-distillate condensation) is shown in Fig. 66, page 163.

Exchangers.—Exchanger condensers, more popularly called exchangers, may be divided into two general classes: (*a*) vapor exchangers and (*b*) liquid exchangers. The former are of special construction and are more generally used abroad than in this country, while the latter class (*b*) find employment in practically every refinery which operates any continuous process where heat is to be added to or removed from the products which are handled. A simple type of exchanger, constructed from an outer shell of 10-inch pipe and an inner surface of 2-inch tubes has already been described. This design is evolved into an apparatus containing thousands of square feet of interchange surface.

Class (*b*) exchangers may be further subdivided according to the nature of the crudes on which they are designed to operate. The latter may be: (1) light crudes where vapors are evolved at comparatively low temperatures; or (2) heavy crudes containing a considerable quantity of water, where vapors are either not given off in any appreci-

able quantity, or are so entrained with crude as to make a vapor separation at this point impossible. In many refineries the first subdivision takes the form of a still containing many feet of pipe, through which the outgoing fuel oil or residuum is pumped, the incoming crude circulating around the residuum coils in counter-current. In a plant stripping to "off gas-oil" a sufficient degree of heat is often obtained in such an exchanger to vaporize from 3 to 7 per cent of light benzine, depending obviously on the gravity of the crude which is employed. Such a form of exchanger, or as it is often called a settling or exchanging still, has been previously described in specifications for a 6000-barrel refinery. The details of construction are shown in Fig. 68, page 181.

The second division of the class (*b*) type of exchangers, while not differing in principle from the first, is merely a closed counter-current system and makes no provision for a vapor outlet, except as it is entrained in the outgoing heated crude.

In general, an exchanger design involves the following: (*a*) the selection of sufficiently heavy plate and reinforced construction to withstand the sudden stresses often developed in apparatus of this nature, particularly in closed types of exchangers heating above boiling point of water; (*b*) the providing of sufficient contact surface between the two liquids, or liquid and vapor, to secure maximum heat interchange without undue friction or loss in radiation from prolonged passage; and (*c*) the fabrication of the apparatus so that all parts may be readily interchangeable or accessible for cleaning. With reference to (*a*) while no fixed rule can be given, an exchanger designed to withstand 50 pounds pressure, provided with suitable safety or release valves may be generally considered a safe working unit, and the contact surface (*b*) may be computed by the application of the recently discussed formulae. Consider as a typical example, an exchanger for a continuous battery stripping 2400 barrels of 26° Bé. crude daily, producing 26.5 per cent of overhead distillate, including water and loss. Let it be assumed that the temperature of the residuum leaving the end still of the system is 410°,[1] its gravity 18° Bé. (331.2 pounds per barrel); and that the crude is received at 72° (314.4 pounds to the barrel). It is then evident for the maximum interchange of heat that:

$$(100-26.5)\times 331.2\times .4(410-t)=100\times 314.4\times .5(t-72);$$
$$3,992,284-9,737.3t=15,720t-1,131,840;$$
$$5,124,124=25,457.3t;$$
$$t=201.2.$$

where 0.4 = specific heat of the residuum;
.5 = specific heat of the crude plus water;
t = final temperature of residuum and crude for maximum heat interchange.[2]

Then

$$H=\frac{F_W\times S\times(t-t_1)}{K\times\theta_m}$$

where H = total heat exchanging surface in square feet;
F_W = weight of crude passing per hour $=\frac{2400\times 314.4}{24}=31440$;
S = specific heat of crude plus water = .5;
$t-t_1$ = temperature crude leaving exchanger minus temperature crude entering exchanger $=201.2-72=129.2$;

[1] This figure may be derived from the distillation test of the crude, taking the temperature of the residuum after stripping 26.5 per cent.

[2] The final temperature (t) of equation balance may be greater or less than results obtained in actual operation, due to partial fractionation, varying percentage of water, absorption of heat by metal of exchanger, etc.

K = B. t. u. per hour per square foot per degree mean temperature difference = 10;[1]

θ_m = mean temperature difference[2]

$$= \frac{(410.0-201.2)-(201.2-72)}{\log_e \frac{410.0-201.2}{201.2-72}}$$

$= 166.1.$

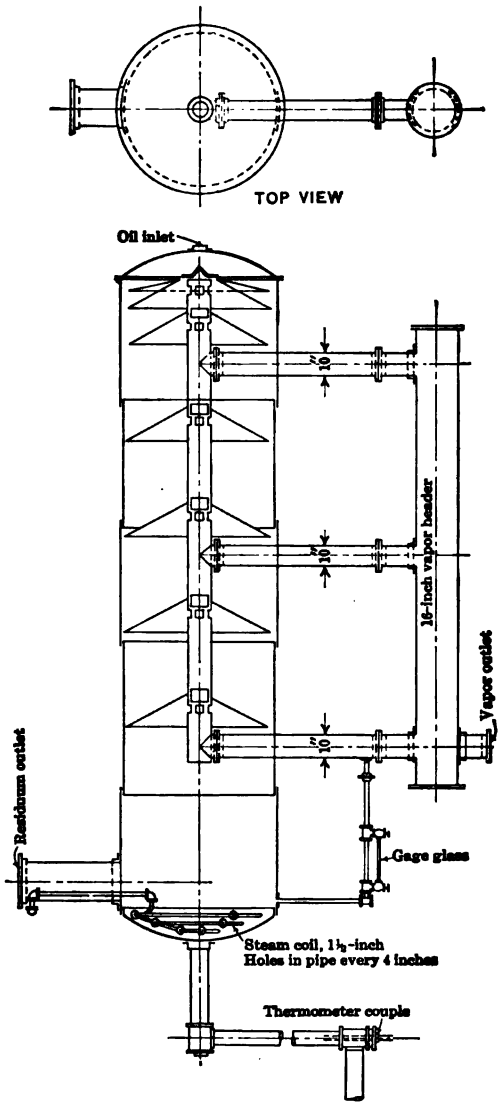


FIG. 69.—Vertical section of an evaporating column 6 feet in diameter by 25 feet high.

[1] See p. 161.

[2] 10–15 B.t.u. per hour per square foot per degree of mean temperature difference has been found to be the most practical basis for exchanger design.

Substituting,

$$H=\frac{31{,}440\times.5\times129.2}{10\times166.1}=1223 \text{ square feet.}$$

In actual construction such a surface might be obtained by a 4-inch pipe inside of a 6-inch jacket, the smaller unit to carry the residuum and the larger the crude, although other convenient forms might suggest themselves in actual practice modified by local conditions. Whatever form of design is adopted, however, provision should be made for adequate insulation so as to reduce radiation loss to a minimum.

Towers.—While this case of refining apparatus is for the most part special, the adoption of separating towers has become general in the stripping of heavy moisture-bearing crudes and the application of dephlegmating columns to steam stills is practically universal. This subject will therefore be partially covered at this point.

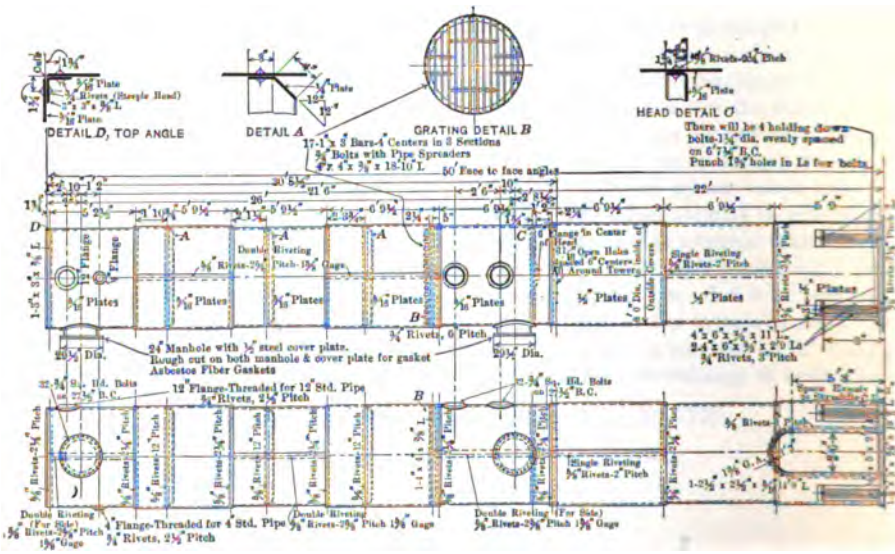


Fig. 70.—Details of a separating tower for steam and combination stills.

In general, crude separating or evaporating towers are cylindrical vertical shells, from 4 feet to 10 feet in diameter and from 20 feet to 40 feet in height provided with baffles or dephlegmating basins at various levels. Such towers are usually further fitted with a steam coil at the bottom. A vertical section of such a separating tower, which may be taken as a type, is shown in Fig. 69, page 183.

Steam still towers are generally constructed of practically the same dimensions as separating columns, and are often fabricated in the same manner. Fig. 70 gives details of such construction, as applied to a combination still. However, the general practice for strictly steam still towers is to eliminate baffle plates and replace them by broken stone, crocks, or special stoneware shapes, designed to increase the contact surface and entrain particles of liquid as dephlegmation takes place. The specifications for a typical steam still tower have already been given in an earlier paragraph. Towers of this order are sometimes erected on supports apart from the still, more often on a bridge immediately over the still, and are frequently framed to the shell of the still itself, with the maximum diameter of the tower opening for

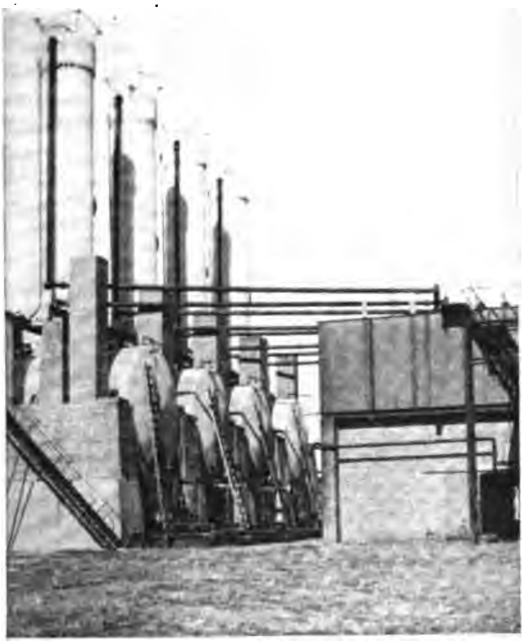


Fig. 71.—Rear-end view steam stills, showing towers and condenser.

Fig. 72.—Steam-still towers.

vapors. Fig. 71 illustrates the actual appearance of such a standard type of steam still tower erected in battery on bridge supports. Fig. 72 is another form.

Agitators.—Agitators may be classified according to the purpose of their use, as, (*a*) light oil, for treating gasoline, benzine, kerosene, etc.; (*b*) lubricating oil, for treating paraffin distillate, pressed distillate and lubricating oils in general; (*c*) tar, for treating dry-run tars, heavy reduced crudes, etc. Class (*a*) agitators vary in size from 250 to 5000 barrels. Specifications for 375- and 2500-barrel units have already been included in a previous paragraph, the last size mentioned being further illustrated in Fig. 73. Fig. 74 shows the details of construction for a 375-barrel agitator. Attention is called especially to the lantern-type roof of 1500-barrel unit, in Fig. 75, pages 188 and

FIG. 73.—A 2500-barrel agitator.

189, which affords a large relief area in case of explosion. Agitator cones of class (*a*) type vary from 60 to 15°, the more desirable sharper angle being impossible in the units of larger diameter, as the depth would be prohibitive for efficient agitation. The cones are braced in the smaller sizes with from four to six pipe supports of suitable weight, these being replaced by trussed angle frames as the size increases, to reinforced gusset plates in the larger units. Roofs are invariably of self-supporting type, cone, globe, or hemisphere in the smaller sizes, globe in the larger. Fig. 76, page 190 illustrates the appearance of hemispherical roofs.

In general, light-oil agitators should have rivets countersunk for lead lining. These should usually be applied in vertical sheets hung from the top of the agitator, and in the larger sizes should be supported again midway on the shell. A 3-inch lap is ordi-

narily employed on the shell (6-inch at the bottom where the cone segments join). The latter are made up in six or more segmental units depending on the size of the bottom and are burned to the side sheets and a central saucer sheet. This in turn is joined to the neck section passing through the cast iron outlet and is flanged over at the bottom.

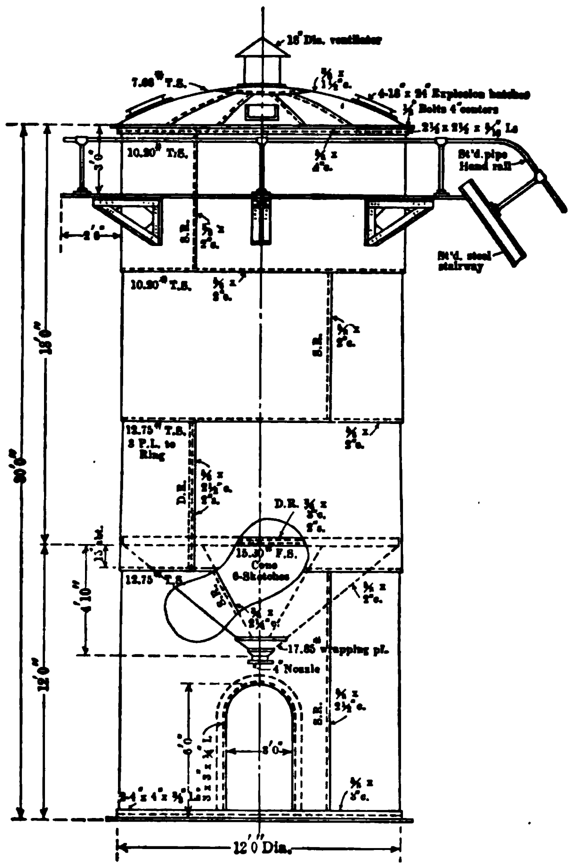


FIG. 74.—Details of a 375-barrel light-oil agitator 12 0 diameter by 30.0°.

Chemical or antimonial lead (Hoyt metal) is used for lining, generally in the following weights:

	Sides	Cone	Saucer	Neck
Antimonial lead......	10 pound	12 pound	12 pound	15 pound
Chemical lead........	8 pound	10 pound	10 pound	12 pound

There is some difference of opinion among refiners as to the efficiency of one type of lead as compared to the other. The antimonial lead is somewhat higher in price per pound, but a longer life is claimed for less weight. It has been the writer's observation that the extra cost of the antimonial product is not offset by any noticeable gain in the life of the lining where fresh acid and weak lye solutions are used, but it is undoubtedly

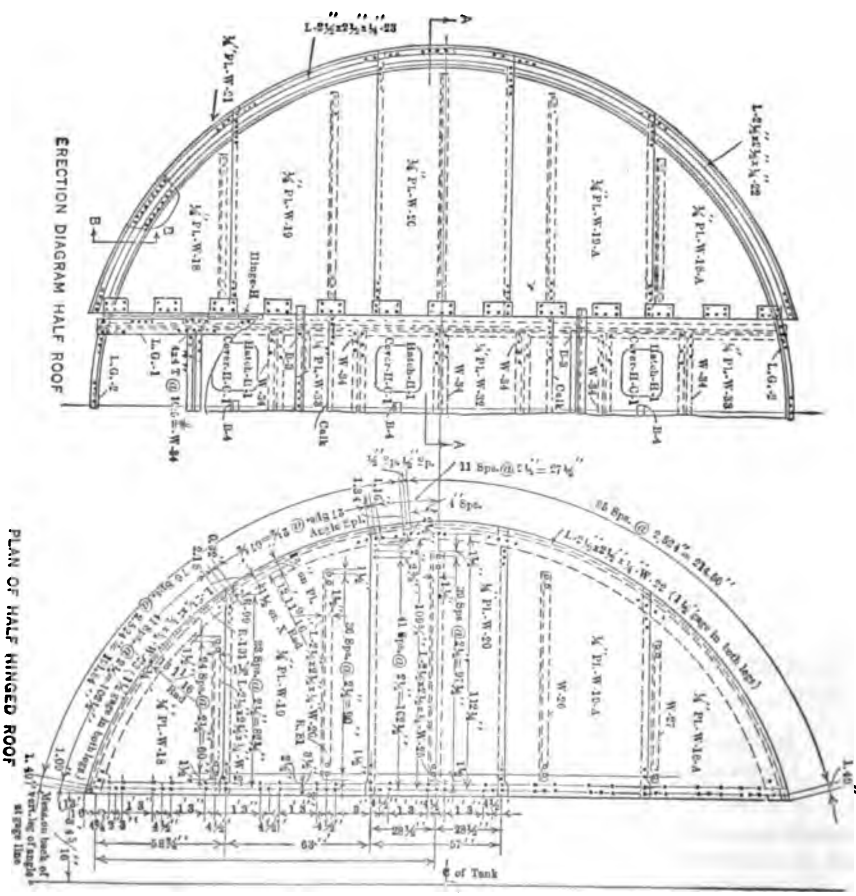


Fig. 75.—Details of the roof of a 1500-barrel agitator.

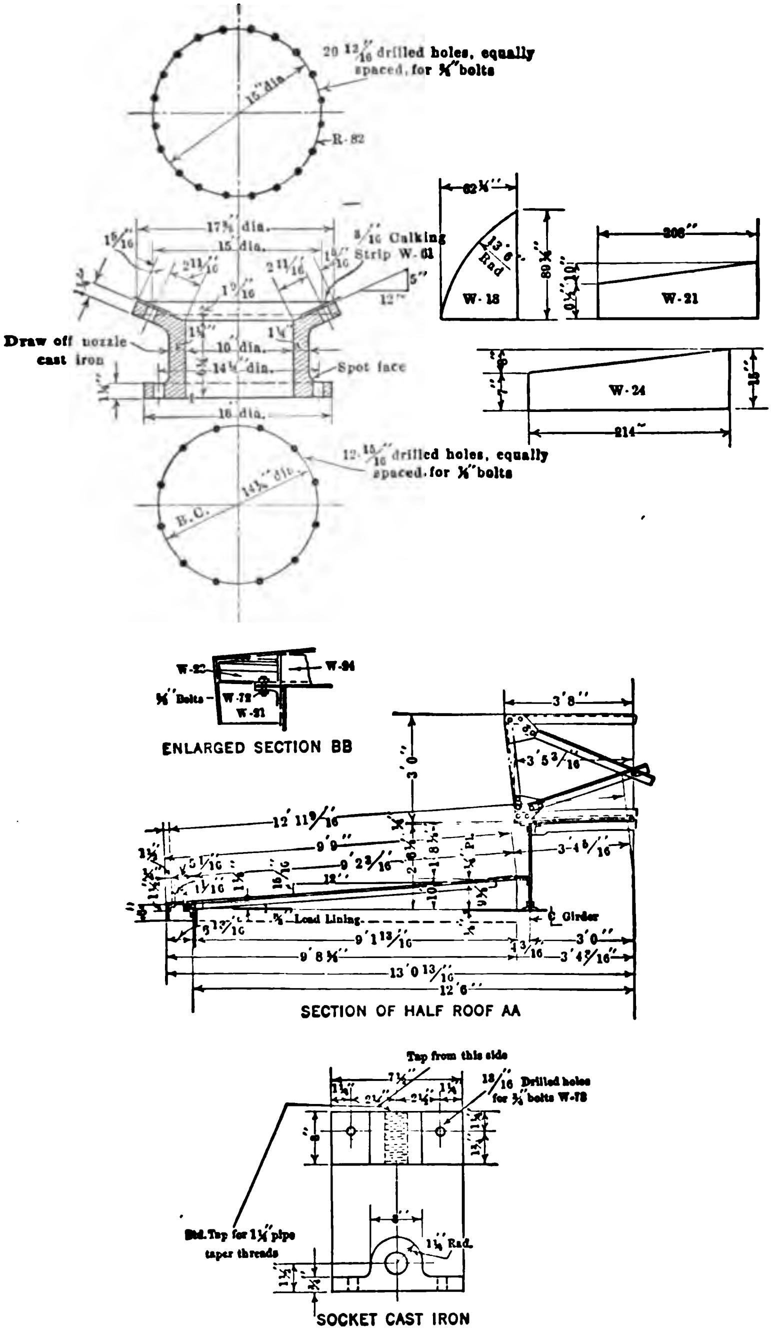


Fig. 75.—Details of the roof of a 1500-barrel agitator.

highly advantageous where restored acids or strong "doctor" solutions of 15° or higher are employed.

Lubricating agitators, class (*b*) may be further subdivided into treating and neutralizing units. They are built in units from 250 barrels up, extra large sizes being avoided on account of the necessity of maintaining a sharp angle of cone. Treating agitators, unless used for extremely light lubricating oils are never lined, while neutral-

FIG. 76.—Agitators with hemispherical roofs.

FIG. 77.—Agitators with enclosed tops.

izing or wash agitators are lined or not lined at the option of the refiner. The method of neutralizing has much to do with the advisability of lining. On account of the necessity of frequent sampling and the desirability of keeping out all moisture during treating, it is customary in many sections to house-in the top of lubricating-oil agitators. Fig. 77 gives an idea of the appearance of such construction.

Tar agitators, class (*c*), are usually designed in large units, with special bronze

gates or traps for withdrawing sludge or coke according to the nature of the acid waste. Such agitators have been replaced in part by tower stills, but many are now employed in the treating of fuel or other stock intermediates. They differ little in construction from the standard lubricating-oil treating agitators, lining being rarely if ever practiced in such units. Lubricating and tar agitators are commonly insulated with asbestos, cement, brickwork, etc., or housed in buildings.

Boilers.—Standard return tubular boilers, either in brick or steel-encased setting and with or without special insulating intermediary walls continue to be quite generally used throughout the refining industry, particularly in plants where initial low construction cost must be rigidly followed. Water-tube boilers are used more frequently in the larger plants, or where the initial cost is less considered than future efficiency. Where reasonably soft water is available, they are undoubtedly the most satisfactory type of boiler for general refinery purposes for plants requiring 500 horse-power and upwards.

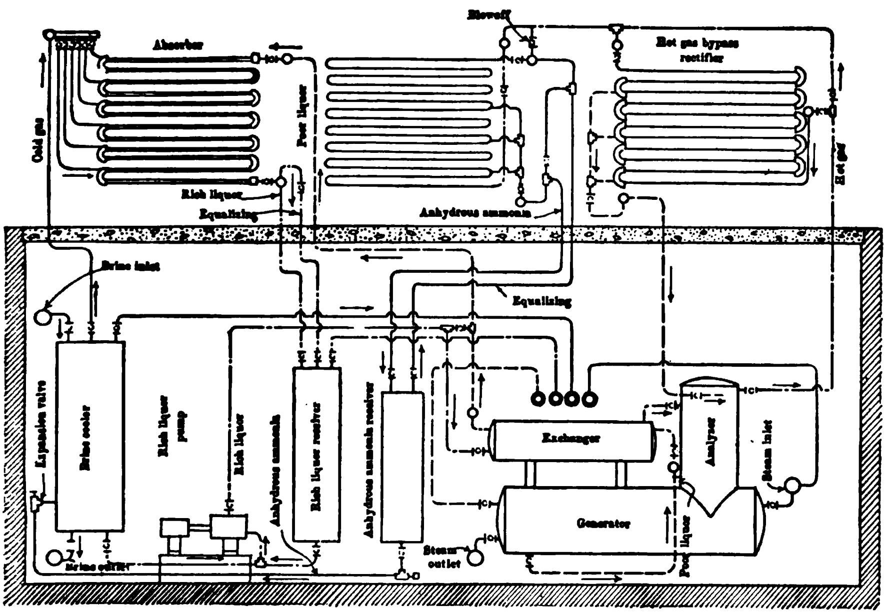


FIG. 78.—Cross section absorption system.

Scotch marine boilers can be used to advantage in a space where it is impossible to erect equal horse-power return tubular or water-tube units, and therefore they often occur as replacement boilers in the older plants where additional power is required, without allotting further space to the boiler plant. It is, however, at once apparent that the selection of the number and type of boilers is an individual problem for every plant, depending on the process to be employed, the nature of the fuel, and the amount of investment involved. It is obvious that in a plant of large capacity making a full line of products, where the amount of steam consumed is considerable, every device for promoting efficiency about the power plant should be employed. This does not mean, however, that the problem can be slighted in a plant of small capacity.

In computing the necessary boiler horse-power, it should be noted that it is generally possible to utilize a portion of the hot overflow water from the condensers, as well as the exhaust steam from the pumps, drips, etc., and so materially cut down

live steam requirements. Economizers may sometimes be installed to advantage in connection with the waste heat gases from certain types of stills, and steam may also be used for the process after it has performed work in turbo-generators. Great care should therefore be exercised in computing steam needs, it being often possible to cut the original estimate by 15–25 per cent after considering the modifying features that are mentioned above.

Wax-plant equipment.—Refrigerating units employed in wax-plant equipment may be classified according to (*a*), the type of gas that is used to effect refrigeration, and (*b*), the method of operation, i.e., compression or absorption system. With reference to (*a*), while carbon dioxide and sulphur dioxide are used in refinery practice abroad

FIG. 79.—Brine cooler and absorption coils.

and give excellent results, ammonia is more frequently, and in this country practically universally, employed. The compression system, formerly used to a considerable extent in refinery operation, is being gradually displaced by the absorption method. Practically all recent installations of any appreciable size are of the absorption type, the high temperature exhaust from turbo sets, now so frequently installed, being ideally suitable for low-pressure absorption systems. Such an arrangement is shown in diagrammatic cross section in Fig. 78, page 191, while Fig. 79 illustrates the brine cooler, absorption, condensing and rectifying coils of a typical refrigeration unit. The selection of proper-sized refrigeration equipment for wax-plant operation is dependent on the pressure of steam, the temperature and quantity of cooling water, the nature of distillate to be pressed, and lastly the temperature at which the latter will be received and delivered. The problem is somewhat intricate of solution,

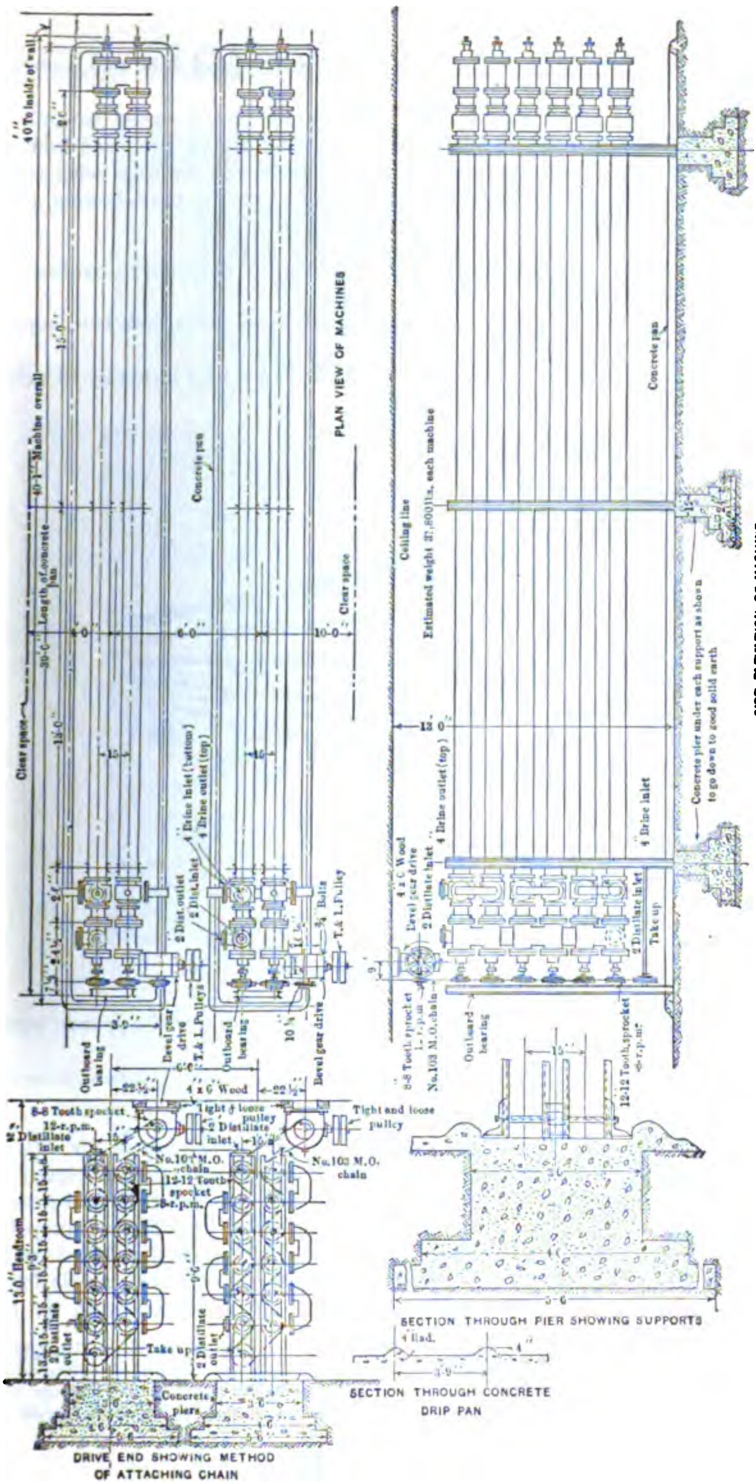


Fig. 80.—General arrangement (2) 12-section Carbondale chilling machines.

involving various heat interchange formulæ and much empirical data, and is obviously a matter for expert advice.

For instance, the specifications for a refrigerating unit designed to chill 1000 barrels per twenty-four hours, of wax oil or paraffin distillate produced from a 37-gravity Mid-Continent crude, with steam at 25 pounds, the distillate being received at 90° F., and delivered from chillers at 10° F., would require the following as principal items:

1 125-ton [1] refrigerating machine, complete with generator, absorber, brine cooler, atmospheric coils, etc.
4 12-section chilling machines, complete with bevel gears, link belt, supports, etc.
2 Ammonia pumps, steam-driven type, size 14 inches by 7 inches by 16 inches.

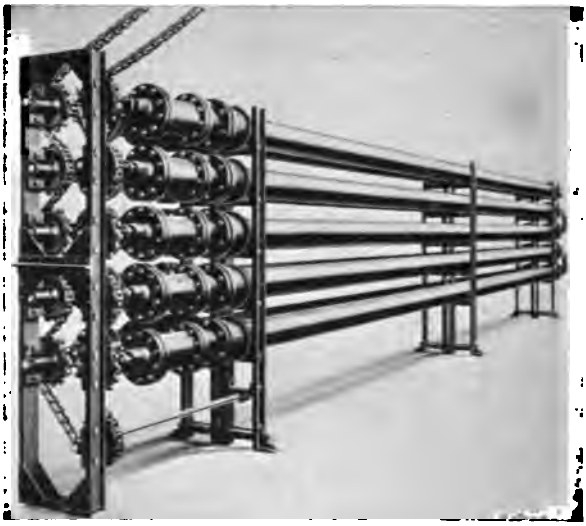


FIG. 81.—A Vogt chilling machine for wax plant.

2 Soft wax pumps, triplex type, size 3½-inch by 8-inch, for 675 pounds working pressure.
1 Brine pump, triplex type, size 8 inches by 10 inches, for 150 pounds working pressure.

The general arrangement of tubular chilling machines is shown in Fig. 80, page 193. The principle of construction consists in a series of double parallel pipes joined together with heavy cast-iron fittings. The inner or distillate-carrying pipes are provided with revolving helicoid conveyors, which scrape the walls, and granulate and propel the wax forward. The larger or jacket pipes are arranged to receive the chilled brine in counter current to the distillate. A variation in construction is to provide for the direct expansion of the ammonia to the jacket coils, and to dispense with the brine

[1] A ton of ice-melting capacity or ton of refrigeration is equivalent to the absorption from the refrigerator of 200 B.t.u. per minute. A 125-ton machine would therefore have an ice-melting capacity of 25,000 B.t.u. per minute, or as it would be ordinarily expressed in wax plant terminology, would have the capability of cooling 625 gallons per minute of 1.25 specific gravity calcium chloride brine from 5° to 0° F.

cooler entirely. This method, while somewhat increasing the efficiency of operation, is more difficult of uniform control, and has not been generally adopted. The actual

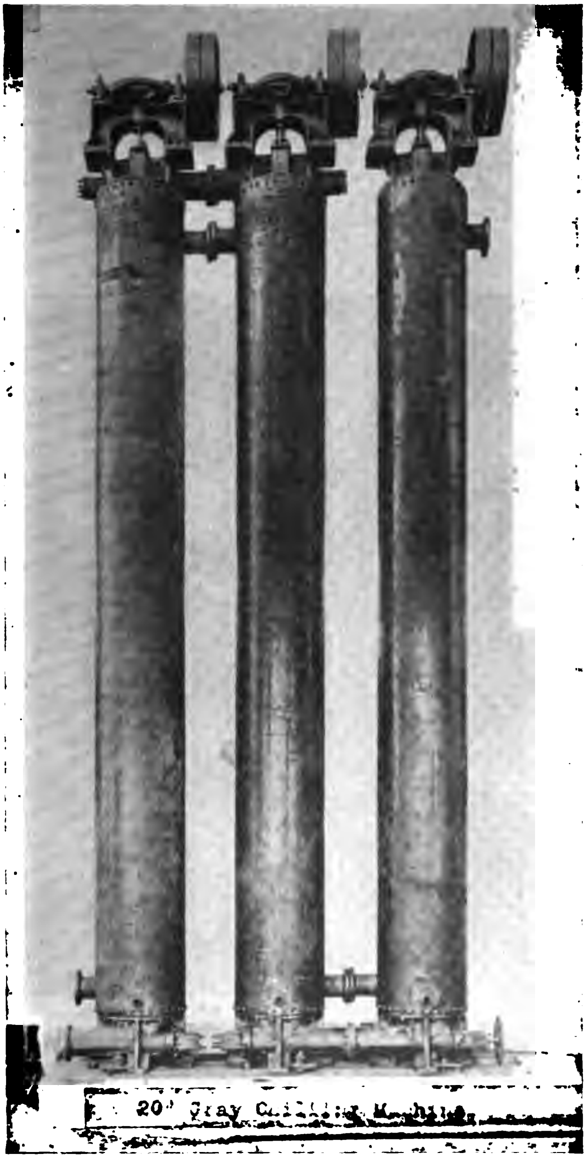


FIG. 82.—A Giay chilling machine.

appearance of a tubular chilling machine is illustrated in Fig. 81, while an entirely different type of machine is shown in Fig. 82. Ammonia pumps are illustrated in Fig. 83, page 196.

To separate the slack wax from the chilled distillate, there would be required in the 1000-barrel plant under discussion the following items:

6 Soft wax presses, carrying 400 48-inch plates with ½-inch rings, presses to be complete with receding drip pan, helicoid wax conveyor, etc.; plattens to be actuated under piston capable of delivering 800 pounds pressure; plates and tension rods constructed to stand a filtering pressure of 500 pounds.
2 Pressed distillate pumps, triplex type, size 5 inches by 8 inches, for 75 pounds working pressure.
1 Slack wax pump, as above.
1 Ram pump, triplex type, size 2½ inches by 8 inches, for 1500 pounds working pressure.

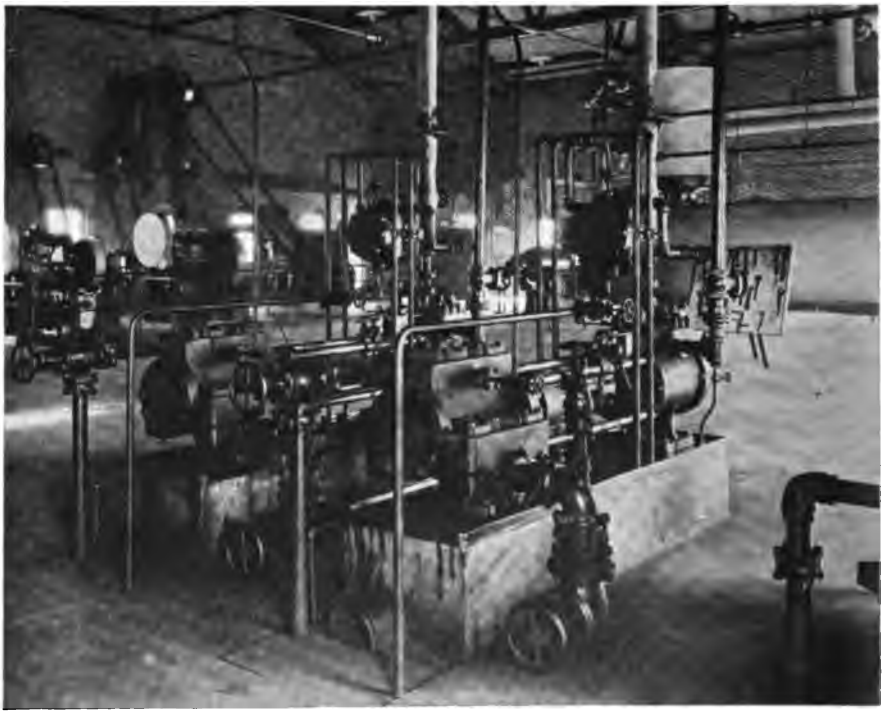


FIG. 83.—Ammonia pumps and generator for wax plant.

The general arrangement of presses, together with the refrigerating units, chilling machines, pumps, etc., for a 125-ton wax plant such as is discussed in the foregoing paragraphs is shown in Fig. 84. The detail of the presses themselves is given in Fig. 85, page 198. The actual appearance of somewhat similar presses is illustrated in Figs. 86 and 87, page 199. From these it will be noted that this type of press in general comprises a heavy cast-iron head and ram, joined together by two steel rods extending from end to end. Between, and supporting the latter, are located, at equal intervals, suitable brackets, while resting on rods are plates and rings in alternate units. The latter are set up by a hydraulic ram so constructed as to deliver 800 pounds

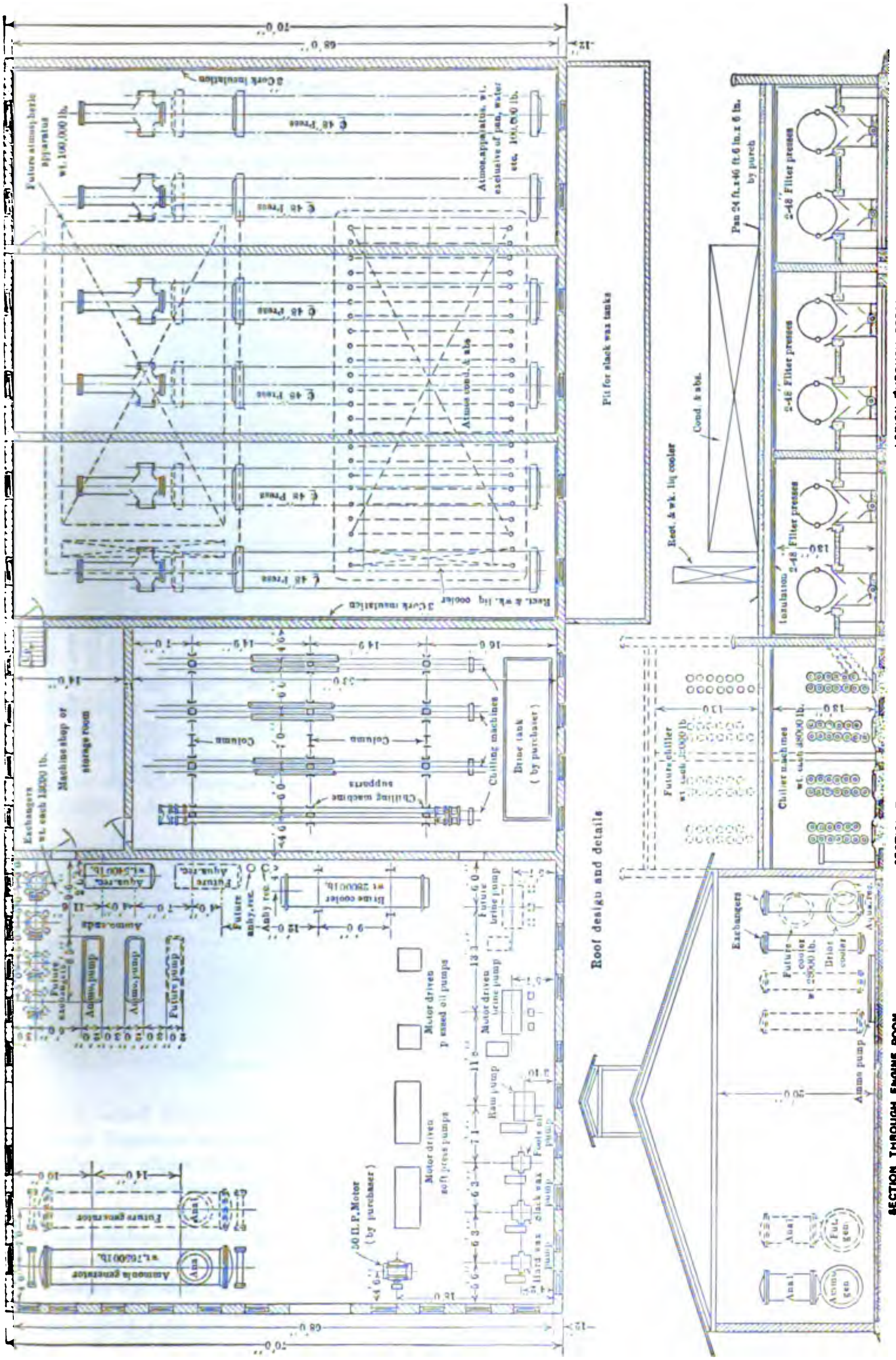


Fig. 84.—General arrangement 125-ton wax plant.

pressure per square inch, through the agency of a movable platen attached to the piston head, and carried on the steel rods previously mentioned. The platen head is cast with eight equidistant holes near the circumference, which allow the passage of corresponding tension rods, on the ends of which are screwed heavy hexagonal nuts after the press is made up. The strain on the ram is thus diverted, and the latter is relieved from further duty until it is desired to take down the press. Feed is through the head and down the center of the plates. The latter are formed of ⅛-inch steel to which is riveted on either side by aid of spacing bungs, heavy 12-ounce duck over wire screen. Between alternate plates are inserted spacing rings, consisting merely of annular steel hoops, from ⅜-inch to 1-inch in thickness[1] and about 1½ inches wide.

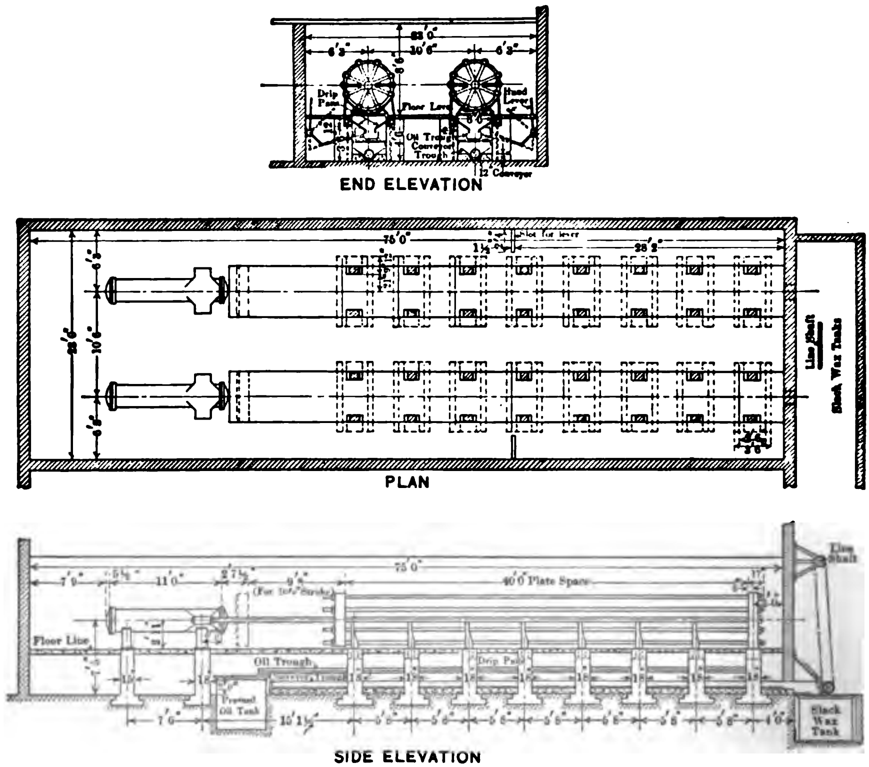


Fig. 85.—Setting plan of (2) 400 plate Carbondale soft wax presses.

They, like the plates, are provided with twin lugs for support on the main frame rods. A variation in this method is to reinforce the outer circumference of standard duck-covered plates, with a sufficient number of annular rings of the same weight covering, equivalent to half the thickness of the desired wax cake, and thus entirely obviate the necessity for steel rings. Continental practice follows the American press in many instances but is generally limited to smaller units and adopts a pyramid surface cast-iron plate with unattached duck cloths. Greater freedom of flow is claimed for such construction. Other forms of presses employed in refinery practice, although rapidly

[1] The thickness of the spacing rings obviously governs the thickness of the wax cakes, ½-inch rings being the most frequently used in present-day practice.

disappearing in this country, are the hydraulic or hard press, in which a certain amount of oil is removed from the slack wax before the latter is pumped to the sweaters. Such presses are upright, vertical units of standard construction and require little comment since they are being rapidly superseded by various types of sweating apparatus.

The sweating unit most universally adopted in this country and abroad is the so-called "sweating pan," which is of shallow, rectangular construction and is generally

FIG. 86.—A Vogt soft-wax press.

installed in units of six to eight pans in a vertical tier, at equal distances apart, and supported by a structural steel frame. The whole is built inside a substantial brick chamber or "oven" provided with large tight-fitting doors at both ends to afford free circulation or air-tight space as may be desired. Sweating pans vary in size and ratio of width to length. A popular small-sized unit is 8 feet wide by 20 feet long, while a pan 10 feet

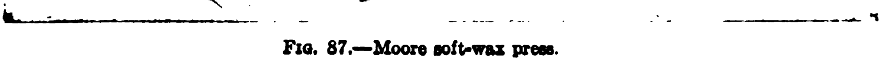


FIG. 87.—Moore soft-wax press.

wide by 40 feet long, shown in detail in Fig. 88, page 200, is much used in the larger plants. Sweating pans in general are provided, about 6 inches below the top, with a false bottom of 8-mesh galvanized iron or brass screen, securely fastened to the sides of the pan by flats or angle iron, and supported on the bottom by suitable bracing. Immediately above the screen are installed water-circulating coils, comprising a series of ¾-inch pipes properly manifolded so as to secure as nearly uniform cooling or heating effect on the charge in the pan as good construction will allow. Uniformity in heat

transference is especially desirable where it is intended to use the hot water system of sweating, which is now quite generally employed. Below the screen is located the melting-down coil, also constructed of ¾-inch pipe with two or more open ends, depending on the size of the pan. This makes possible the rapid melting of the scale on the screen, and also aids in keeping the latter free from gummy deposits which sooner or later accumulate from untreated slack wax. The bottoms of the pans are in general self-draining, one or more flow points being installed according to the length of the pan. Care should be taken to avoid any strains in fabrication that would tend to throw the screen out of level and thereby prevent uniform sweating.

Filter-house equipment.—Specifications for a standard type of filter 8 feet in diam-

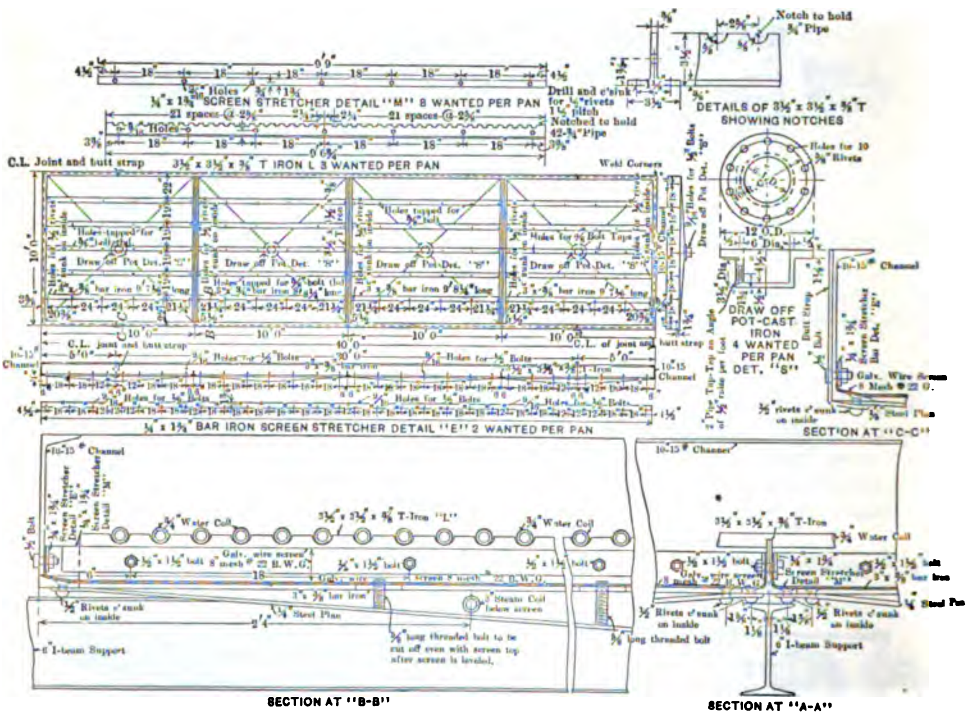


FIG. 88.—Details of a sweating pan, 10 feet in diameter by 40 feet in length.

eter by 20 feet have already been given in an earlier section.[1] Fig. 89 shows the construction details of a filter of similar dimensions, that is provided with a special bottom earth discharge. Since two refiners rarely agree as to the most advisable size of filters, or the ratio of length to diameter, there are obviously no uniform standards of construction. However, it may be said, in general, that filters are usually built in cylindrical form, and while almost any diameter and height can be found in service, units of 5 feet diameter by 10 feet in shell, and those of 8 feet diameter by 20 feet in shell have found considerable favor in various plants. Occasionally filters are constructed in conical form, slightly deviating from cylindrical, in order that the earth may pack tighter and so prevent the channeling of the oil in actual operation. The heads should be either of cone or dished type, the latter being preferable on account

[1] See p. 65.

of the absence of seams. In fact, if it were not for the present high cost of this type of construction a smooth seamless surface throughout would be highly desirable, as it would insure uniform packing and no chance of off-colored oil from the portions of the charge left in the seams. For this reason many specifications call for welding of seams—an excellent idea where the objective is extremely light-colored oils or petrolatum. All mannecks should be of substantial wrought construction, and cast iron should be avoided. This is true particularly in the quick-opening type of manhead with yoke and screw, as serious fires and loss of life have resulted when a plate of this type has let go under excessive pressure. This is likely to occur under certain conditions, during naphtha washing. The swing-bolt type of head is fairly satisfactory in extra heavy cast-iron construction, but may be rendered much safer by being fabricated from wrought material. All necks and plates should be faced for a corresponding distance, to avoid any possible chance of leaks, which are highly dangerous when washing with hot naphtha. For the same reason the flanges should be of boiler type, and the general workmanship of the best. False bottoms may be flat, of segmental plates, resting on suitable angle frames, or of sectors taking the general shape of the bottom. Such a type is more often used in filters with a bottom earth discharge outlet. The

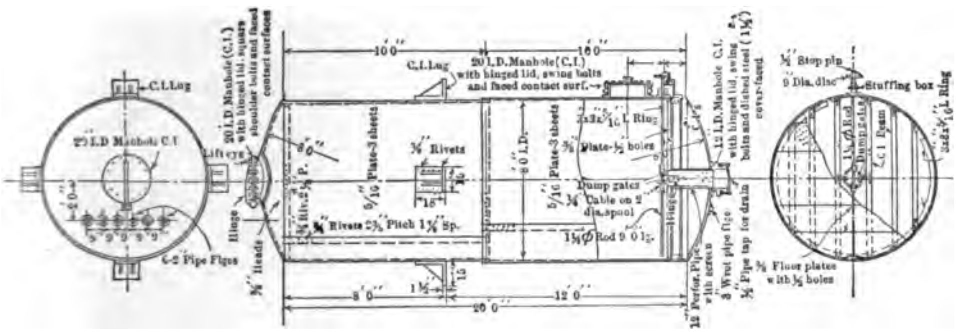


Fig. 89.—Details of a lubricating oil filter 8 feet in diameter by 20 feet in the shell.

latter may be of special construction as in Fig. 89, or a simple cast-iron plug may be used. The plug is withdrawn from the bottom flange when the filter is ready to dump, the cloth immediately above, over the false bottom, being slit with a long-handled knife, and so allowing the charge to empty itself. Where small apertures are used for withdrawing the earth, it is assumed that the latter is washed and steamed dry in the filter. Such practice is practically universal in this country to-day, the older method of transfering an oil soaked charge to a special wash-filter being practically obsolete. A 6-inch opening is amply sufficient to allow the thoroughly washed and steamed dried earth or bone to flow freely, although obviously a filter cannot be emptied so quickly with such an opening as with special gates of larger area.

Filtering media, i.e., fuller's earth or bone char, is handled by the following methods: (*a*) small industrial cars usually running on narrow-gage track and provided with self-dumping bottoms or slide gates, the cars being raised to upper charging levels by ordinary freight elevators; (*b*) belt conveyers provided with traveling hoppers and discharge trippers with bucket elevators for elevating the charge; and (*c*) helicoid steel screw conveyers with swivel discharge legs and elevators similar to those employed in belt installations. Industrial cars and track represent the smallest investment, and for plants handling a minimum quantity of filtering material daily, such a method of transfer can scarcely be improved upon, especially when no extra labor is required for oper-

ation. In many cases cars are used only for handling material on a lower level, and some form of bucket elevator is employed to raise the product. Such an arrangement is ideal where small quantities are handled.

Where filters are being continuously charged and emptied, as in the case of large plants, some form of conveyer system must be installed. The belt system is ideally suited for handling fuller's earth. By the employment of a traveling hopper to receive filter discharge, considerable investment may be saved in storage bins. Then again, a traveling tripper may be used to deflect new or restored earth to the filter or storage bin as desired—an obvious saving in time and labor. On account of the possibility of leaks, or of emergencies requiring the removal of oil-soaked earth from a filter, it is not advisable to make any portion of the belting of rubber which is to carry a discard product. Especially prepared canvas belt is more desirable, although friction-surface rubber belt may be used to advantage in handling new or revivified material. A typical tripper is illustrated in Fig. 91, while Fig. 90 gives an idea of the actual appearance of a belt-conveyer system with the tripper in active operation.

FIG. 90.—Hand-propelled tripper with two-way spout.

Where large quantities of material have to be handled, and investment is to be held at a minimum, the helicoid screw conveyer may be employed. On account of the slightly abrasive nature of fuller's earth, together with the fact that it is quite readily reduced to a powder form, helicoid conveyers are not recommended. Where they are installed the bearings should be constantly watched and excessive duty prevented as far as possible, since a greater grinding action takes place under such conditions of service. Belt conveyers may often be used on long stretches in connection with helicoid screws for short lengths of travel. A system of this type will cost little more than a straight helicoid conveyer installation, and the grinding action on the earth will be scarcely greater than that produced by an all-belt design. Such a form of equipment is shown in erection detail in Fig. 92, page 204, and has given fairly satisfactory service in actual operation.

While bone char was originally used almost exclusively in filtering mineral oils and petrolatum, it has been almost entirely displaced by fuller's earth, and many types of re-

vivifying furnaces have been evolved as a result. In the early days of the industry, revivifying furnaces consisted simply of an open reverberatory arch, provided with a draft stack, and bone char was often burnt entirely in the open. In either case, hand manipulation played an important part, from the stirring of the charge to the placing of it in cans to cool. This crude method was early superseded by a furnace consisting of a series of gas- or coal-fired vertical cast-iron tubes, about 10 feet long, by 18 inches by 4 inches wide, of ½-inch metal, the tubes resembling in cross section an elongated O. These tubes were fed by a suitable hopper at the top of the retort, and were discharged into air-cooled pipes at the bottom, from which finished revivified material was withdrawn at regular intervals. The capacity of such a furnace was obviously limited, and the cast-iron tubes became in time either burned out, warped, or closed, interfering with

FIG. 91.—Belt-conveyer installation showing trippers in operation.

the flow. Patented open types of furnace where free flame came in contact with the material to be revivified, soon made their appearance, especially as bone, with its necessity for the exclusion of air or at least a reducing flame atmosphere during revivifying, became less and less used. While many open-type burners have been designed, only two distinct classes really exist: First, vertical or angle gravity-drop furnaces, in which the material to be revivified either drops vertically through baffled passages, or slides over a series of slopes, in each case meeting free flame and leaving the apparatus burnt free of carbonaceous impurities; second, furnaces of rotary type, installed at a slight angle to the horizontal. The earth is fed into them at the elevated end and by the rotation of the kiln it is gradually advanced to the lower outlet, meeting, as in the case of the gravity-drop furnace, a counter-current or flame. While innumerable types of the simple gravity-drop furnace have been designed, and more or less successfully employed, only two will be considered. The New Century burner, shown in detail in Fig. 93,

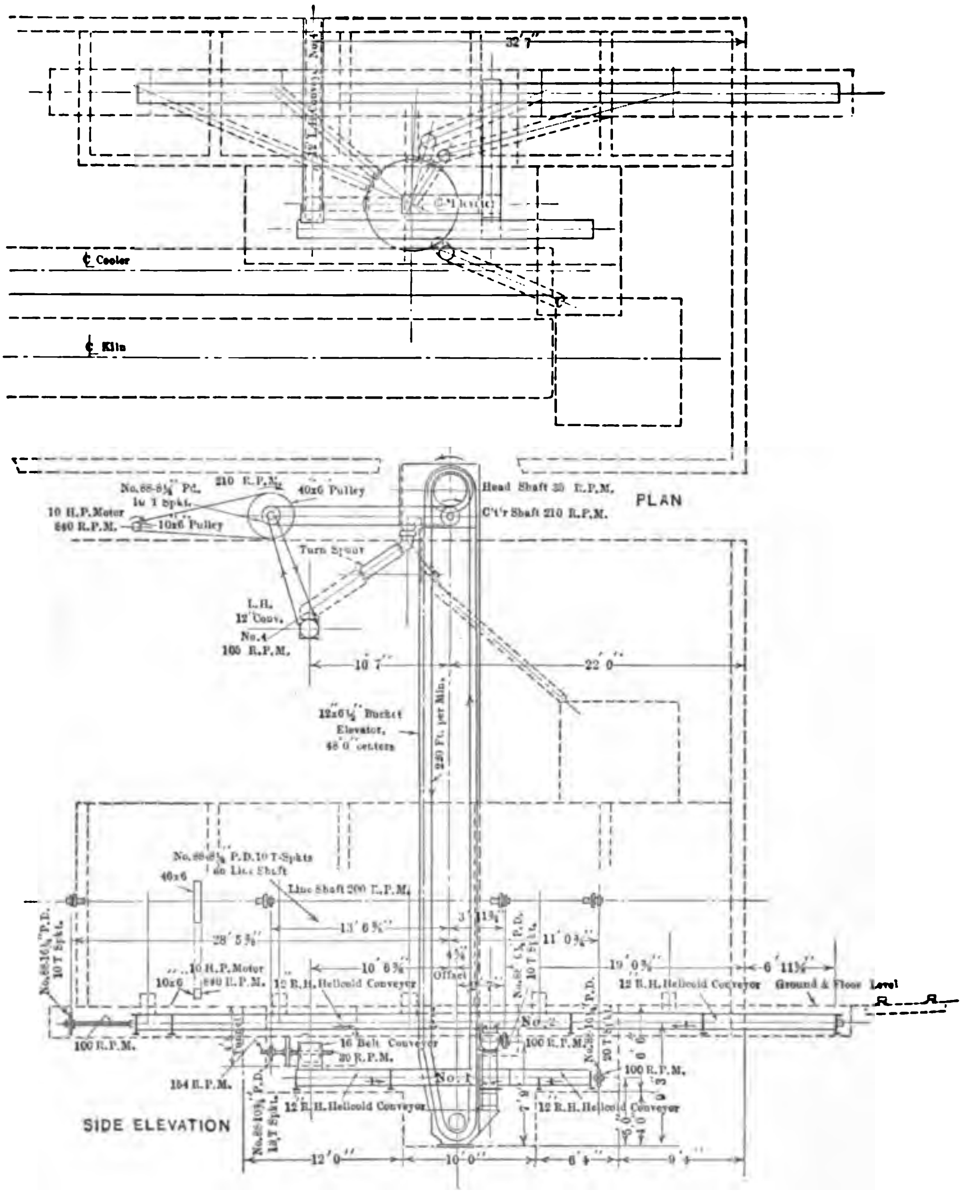


Fig. 92.—Plan and elevation of elevator and helicoid conveyer for handling fuller's earth.

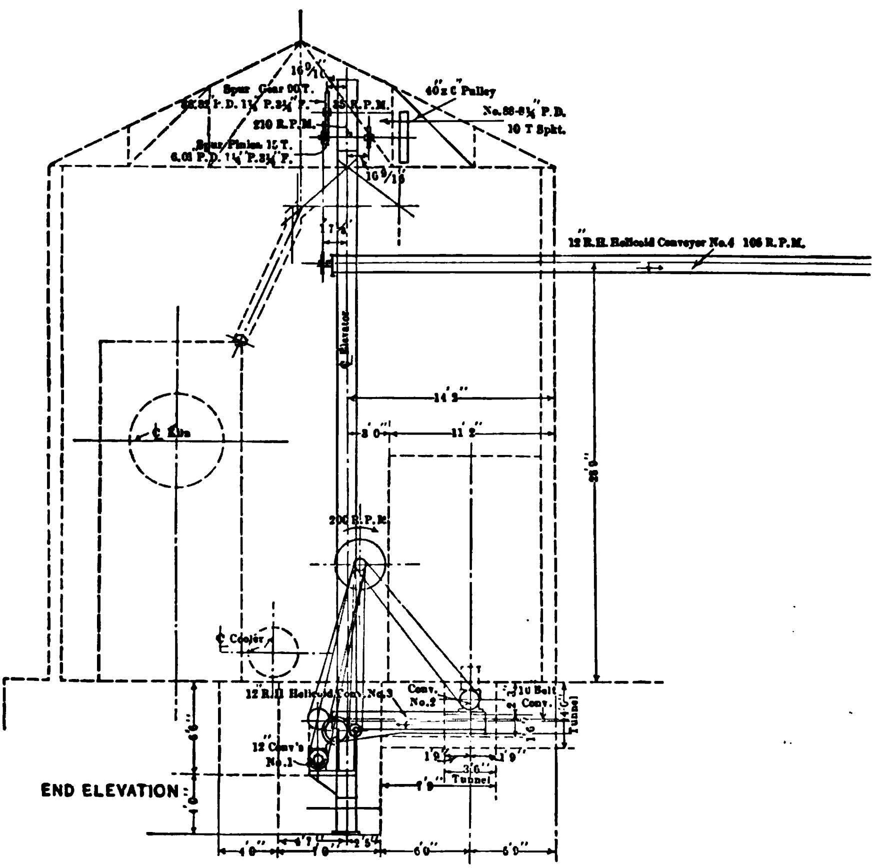


FIG. 92.—Plan and elevation of elevator and helicoid conveyer for handling fuller's earth.

and illustrated in Fig. 94 is typical of a vertical drop furnace. The Richay burner, shown in sectional elevation in Fig. 95, may be considered as an example of the

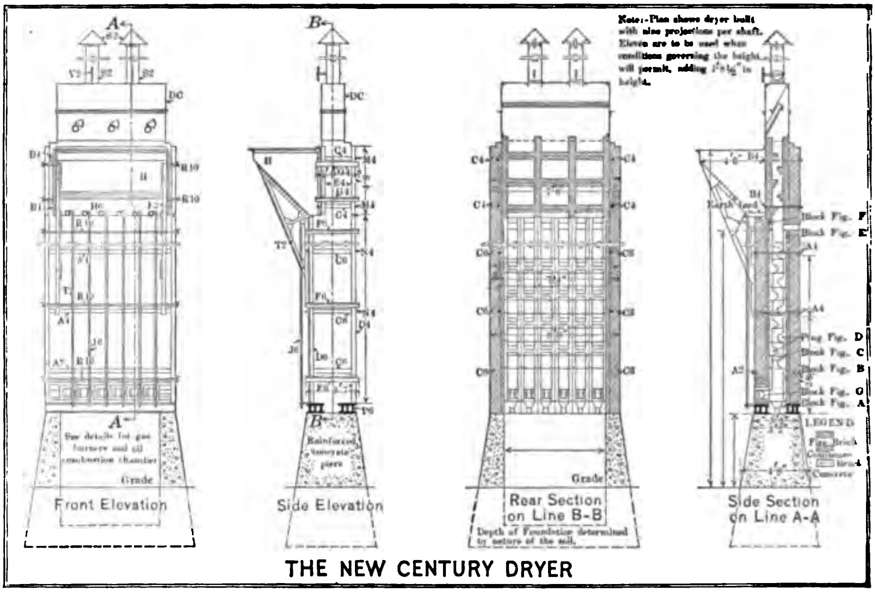


FIG. 93.—Elevations and sections of the New Century earth dryer.

second class of gravity drop burner. Both are self-explanatory as to their method of operation, by reference to the sectional drawings.

The rotating kiln type of burner, together with the rotating cooler shown in sectional longitudinal elevation in Fig. 96, page 208, while representing a rather heavy investment, is often employed by plants handling large quantities of earth. With such a burner there is no chance of clogging from "balling" of the wet earth that may find its way to the retort, a trouble which is sometimes experienced in the gravity-drop type. On the other hand, such a kiln requires special lining blocks, as shown in cross section in Fig. 97, page 208. These in time may work loose and require relining, which is a tedious and expensive operation. The rotary cooler, however, offers no objectionable features, and may also be successfully employed with the gravity-drop furnaces, although other types of water- or air-cooled exchanger coolers erected in vertical position are often used with the latter construction. The operation of a rotary kiln is readily understood by reference to the drawing. It should be noted that the projecting key courses of fire-brick shapes lift the earth through an arc of approximately 120°, the latter falling in an advance position with each rotation.

FIG. 94.—A double unit New Century earth dryer.

Pumps.—Steam pumps may be classified as follows: (*a*) simple, single or double stroke; and (*b*) compound. Both classes of type (*a*) are successfully employed in

many refineries, the single-stroke type probably giving less operating trouble and freedom from short stroke than the more theoretically efficient double-stroke unit. Compound steam pumps are much less used than formerly, their employment being generally

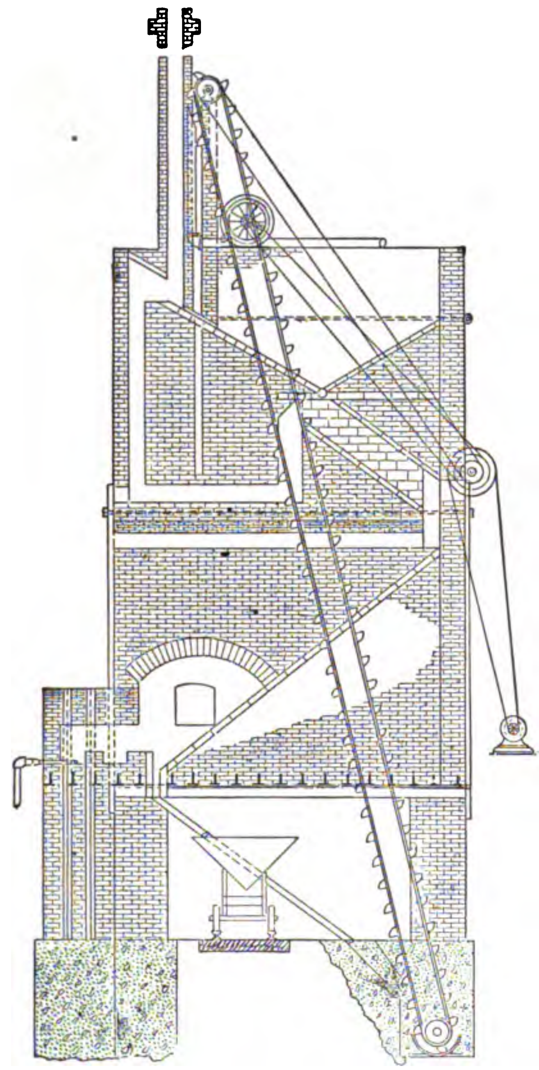


FIG. 95.—Vertical sectional elevation Richay clay and bone furnace.

limited to condensing water-supply units. Power pumps may be divided into the following classes: (a) simplex, duplex, or triplex units, (b) centrifugals, and (c) rotary pumps. Horizontal duplex and vertical triplex pumps, or, as they are called abroad, three-throw pumps, are installed in many plants. The duplex type is preferably employed in the

piston-packed type for use in standard tank transfers under moderate pressures. The triplex units are more often found in wax plants or in other parts of the process where a steady uniform flow is demanded, working under moderately high or severe duty. Such pumps are generally outside packed. Duplex and triplex power pumps are often driven by individual motors, although standard belt or silent chain drives from line

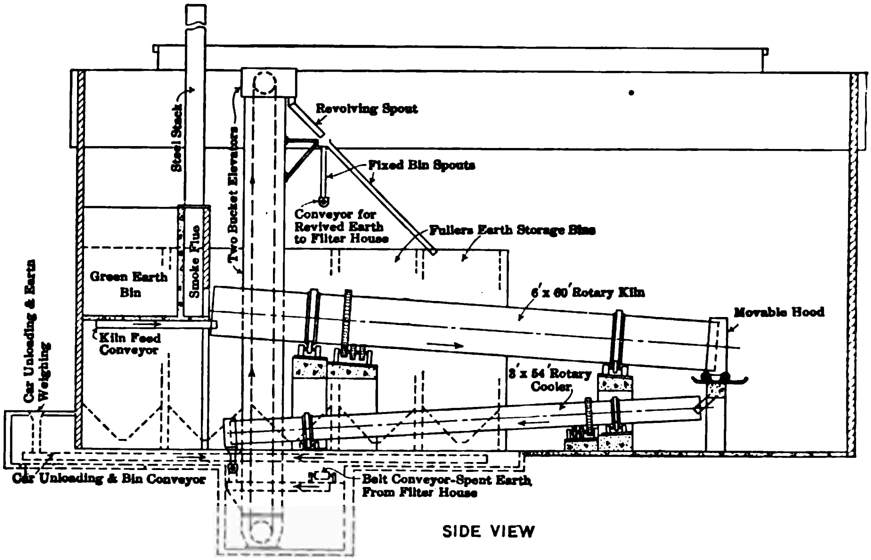


FIG. 96.—Sectional side elevation, rotary earth kiln and cooler.

or jack shaft through the agency of friction clutches, are also employed. Figs. 98 and 99 show all three methods as applied to triplex units.

Centrifugal pumps (*b*) may be classified into, (1) simple centrifugals, with either single or double suction, or vertical or horizontal type, and (2) double or higher stage units, also constructed to operate in vertical or horizontal plane. The simple type of centrifugal pump illustrated in open view in Fig. 100, page 210, may be used as a tank-transfer or loading pump for nearly all[1] refinery products, and is preferable where there is always a flooded suction, although with a priming device such pumps may be used in a variety of locations. They must, however, be selected for standard conditions of service, as otherwise they operate with low efficiency. Their low initial cost is an important consideration, and the fact that their discharge may be shut off against the pump without injury to the same makes them particularly desirable for condensing water circulation. In two- and three-stage units they are used as boiler-feed pumps, and in vertical submerged forms as well pumps. This latter type has

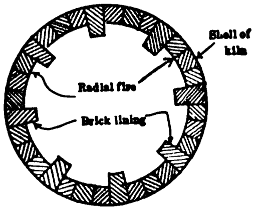


FIG. 97.—An end cross section of a rotary kiln, showing lining shapes.

[1] The use of centrifugal pumps for lighter gasolines is not recommended, operating efficiency being at a minimum, packing difficult to maintain, etc. This type of pump is also unsatisfactory on heavy viscous oils that will not flow freely to suction.

been developed into a highly efficient unit and is illustrated in detail in Fig. 101, page 210.

Rotary pumps (*c*) are manufactured in various designs, involving simple meshing

FIG. 98.—Direct and belt-driven pumps for wax plant.

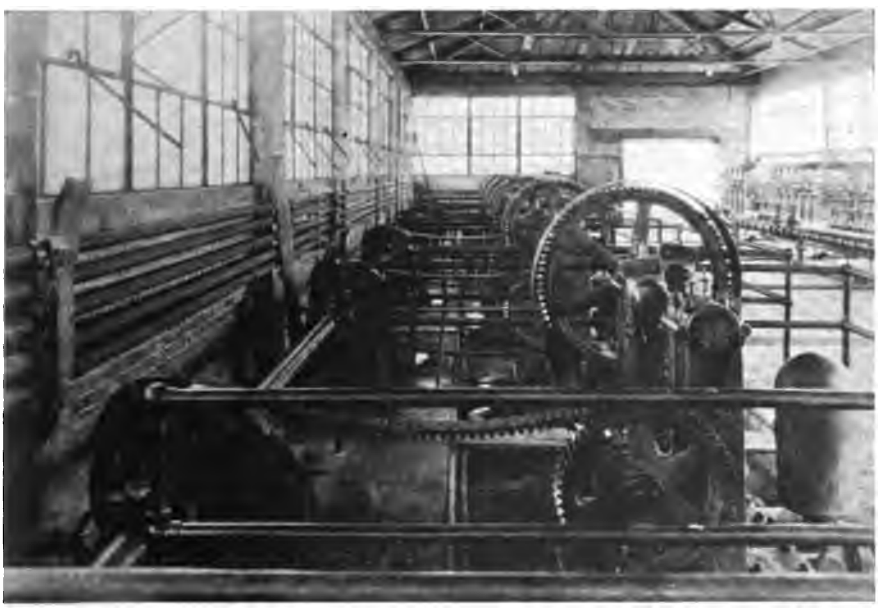


FIG. 99.—Triplex pumps driven from line shaft by friction clutches and silent chain drives.

gears, interlocking vanes and rolling cams. For the most part they find use only in refinery installations, as lubricating pumps for various classes of machinery, barrel

or small tank transfer pumps, and invariably for clean finished products. Fig. 102 illustrates three distinct types. A notable exception to the above statement is the Kinney rotary pump. This is extensively used in large-sized units for handling thick, heavy, viscous oils, such as Mexican fuel and California asphalt flux. The pump is of steam-jacketed construction in the latter instance.

In general, to determine the proper type and size of the pump, as well as the horse-power required for a given objective, the following factors should be known:

(1) Suction lift: the vertical distance from the level of the liquid supply to the center of the pump, to which must be added the loss due to the friction of the fluid in the suction pipe.
(2) Discharge head: the vertical distance from the center of the pump to the center of the discharge outlet where the fluid is delivered, to which must be added the loss due to the friction of the fluid in the discharge pipe.

Fig. 100.—Open view single-stage centrifugal pump.

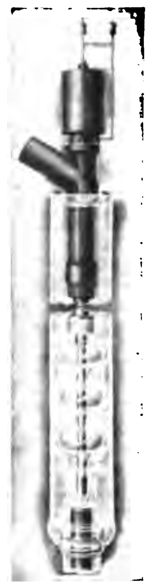


Fig. 101.—A Layne multi-stage vertical centrifugal pump.

(3) Velocity head: $h=\frac{v^2}{64.4}$ where v is the velocity per second of the fluid at the discharge nozzle of the pump.
(4) Total head: the sum of the suction lift, discharge, all friction loss in both the suction and discharge pipes and the velocity head.
(5) Weight of liquid: the product of the specific gravity times the weight of the unit volume of water.
(6) Friction of fluid: a factor dependent upon the size and smoothness of the pipe, the absolute viscosity of the fluid, and the critical velocity of the flow.

The possible suction lift (1), limited to the practical distance of 22 feet at sea level, and unaffected in ordinary computations by daily variations in barometric pressure, is considerably reduced at higher altitudes, as may be readily determined from the appended table, page 212.

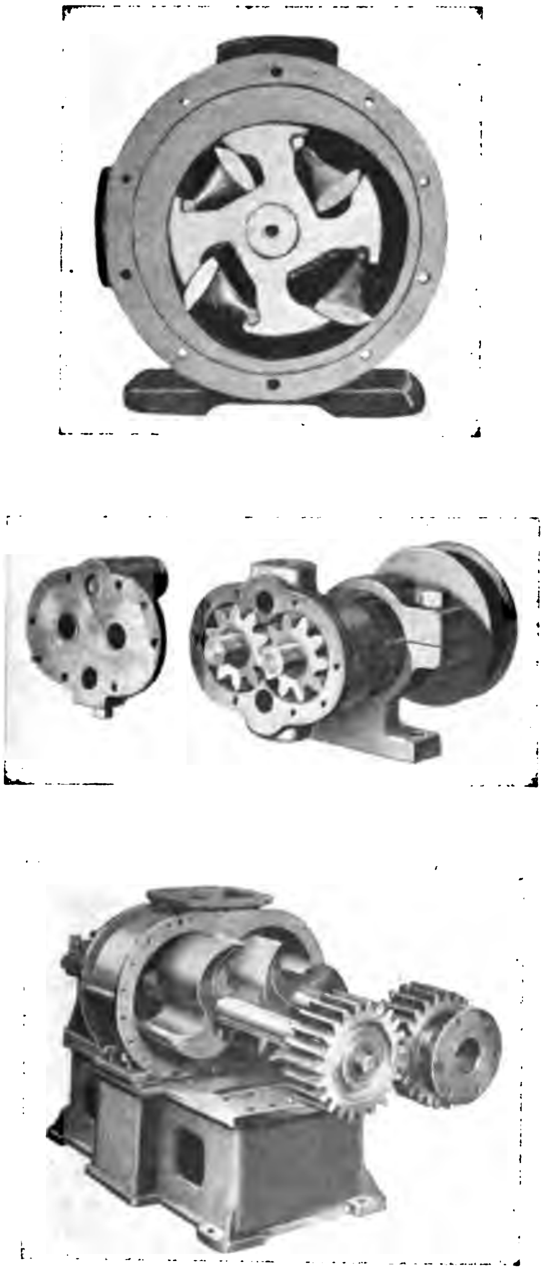


FIG. 102.—Rotary pumps.

Suction Lift of Pumps with Barometric Pressure at Different Altitudes and Equivalent Head of Water

	Barometric pressure, pounds per square inch	Equivalent head of water, feet	Practical suction lift of pumps, feet
Sea level	14.70	33.95	22
¼ mile (1,320 feet) above sea level	14.02	32.38	21
½ mile (2,640 feet) above sea level	13.33	30.79	20
¾ mile (3,960 feet) above sea level	12.66	29.24	18
1 mile (5,280 feet) above sea level	12.02	27.76	17
1¼ miles (6,600 feet) above sea level	11.42	26.38	16
1½ miles (7,920 feet) above sea level	10.88	25.13	15
2 miles (10,560 feet) above sea level	9.88	22.82	14

The friction of the fluid water has been carefully determined for both wrought and cast pipe of various sizes, under different rates of flow.

With respect to centrifugal pumps, it is highly important that the exact operating head including all friction increments be known, since with constant speed an increase in head means a decrease in delivery, and vice-versa. It is obvious, therefore, that if the head has been underestimated, the pump will not deliver to capacity unless the speed of the impeller is increased. This is a manifest impossibility with the ordinary direct-connected squirrel-cage type of induction motor so frequently employed as motive power for this type of pump. Therefore every caution should be exercised in obtaining exact information in regard to operating conditions. If the head be underestimated, it is also true that an overload may be thrown on the motor, generally not excessive with the better class of centrifugal pumps. However, it is always an excellent plan to specify a motor 10 per cent larger than the computed requirements.

Generally speaking, in selecting pumps it should be remembered that the simple steam pump, while often of low efficiency, is also of low initial cost and is adaptable for almost every kind of service at quick notice; that the centrifugal pump, while of low cost, is also of moderately high efficiency, especially when properly selected for unvarying conditions; and that the duplex, and particularly the triplex pumps, while of high initial cost, are of great efficiency. The latter fact is especially apparent in pumps operating at high pressures, 85 per cent being not uncommonly obtained. In short, no fixed rule can be given to govern all conditions, but it is hoped that the foregoing data and the explanations furnished, will be of aid in intelligently solving the pump problem.

IV. SPECIAL APPARATUS

Under this heading will be included certain types of refinery equipment, which in the nature of things cannot be described in detail. There will also be included apparatus which is too infrequently employed, or which, while in common use, is not deemed of sufficient importance to have been included in the chapter devoted to general apparatus.

Tanks.—Apart from the standard riveted steel tanks previously described, the bolted tank has found favor in certain plants, as it may be erected by unskilled labor and requires no other tools than a monkey wrench. This type of tank is generally con-

structed with a steel bottom made up of rectangles and sketch plates. The latter are flanged over to receive side sheets, which are usually in sections 4 by 6 feet wide, extending from the top to the bottom of the tank. The roof is also steel, of self-supporting type. All sheets are properly scarfed at joints and provided with necessary laps between which gaskets are inserted before bolting together. The seams are generally painted with shellac on the inside, after erection, to secure additional tightness of the joints. A variation in construction is to flange-out the vertical edges of the side sheets so that bolting together may be done entirely from the outside. This type of tank was designed primarily as a quickly erected, easily dismantled field running unit; but where care has been used in assembly it has given fair service as a run-down and moderate-sized storage tank. A well-known make is illustrated in Fig. 103.

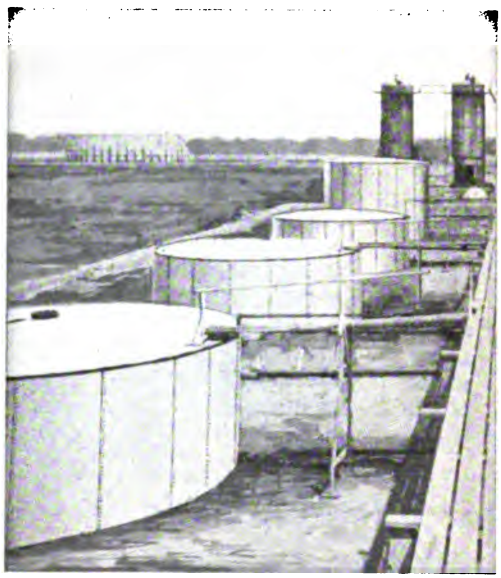


Fig. 103.—Maloney bolted tanks.

Wooden tanks find employment in refinery practice as water tanks for boiler-feed or treating purposes, and also for the storage of the aluminum sulphate solution used in foam installations. Such tanks should be made from cypress, yellow pine, white cedar or fir, and are generally built in vertical cylindrical form with a taper of 1 inch to the foot. Nominal capacities are based on a large inside diameter, so that the actual content is somewhat less than the apparent rating. The appended table of specifications covers the sizes most used in refinery construction. See page 214.

Stills.—Apart from the pressure stills, which are described in another division of this volume, the greatest deviation from standard design is found in the various types of continuous reducing and tower stills. In these the process is so intimately related to the apparatus, that it is difficult to describe the latter apart from the former. Of the many varieties of special reducing stills, the Trumble[1] pipe still deserves special mention. In brief, each unit comprises two furnaces, with three fireboxes, containing seventy-two 4-inch by 18-inch standard pipes in six horizontal rows. Only the two lower rows are exposed directly to the radiating heat from the fires, the others being heated by the flue gases which ascend through a lateral passage, and serve also to heat the evaporator. The latter is a vertical, cylindrical tank 6 feet wide by 25 feet high, and is situated in the stack between the heaters. The general arrangement is shown in Fig. 53, page 148. Internally the evaporator is equipped with seven conical baffle plates, supported by a 12-inch vertical central vapor line, which in turn is supported by three 10-inch lateral vapor off-takes passing through the shell of the evaporator. The crude enters at the top and flows over each baffle in turn, thus being constantly directed against the heated shell. The vapors pass into the vapor lines through 4-inch

[1] The following description embraces the Trumble pipe still as developed by the Simplex refining department of the Shell Company of California, San Francisco, California.

Specifications for Standard Wood Tanks *

(With 1-inch taper to the foot)

Nominal capacity, in gallons	Inside diameter, feet inches		Inside depth, feet inches		Number of hoops	Weight, 2-inch cypress, pounds	Weight, 2-inch yellow pine, pounds	Weight, 2½-inch cypress, pounds
3,531	8	0	9	5	8	1660	2195	
4,281	8	0	11	5	10	1971	2542	
4,479	9	0	9	5	8	1865	2485	
5,429	9	.0	11	5	10	2242	2877	
6,706	10	0	11	5	10	2539	3405	
7,880	10	0	13	5	11	2897	3973	
9,658	12	0	11	5	10	3164	4197	
11,350	12	0	13	5	12	3637	4625	
13,042	12	0	15	5	13	4150	5301	
15,449	14	0	13	5	12	4382	5714	5825
16,600	14	0	15	5	14	5038	6517	6643
17,171	16	0	11	5	10	4578	5976	6093

* Adapted from specifications of W. E. Caldwell Company of Louisville, Ky.

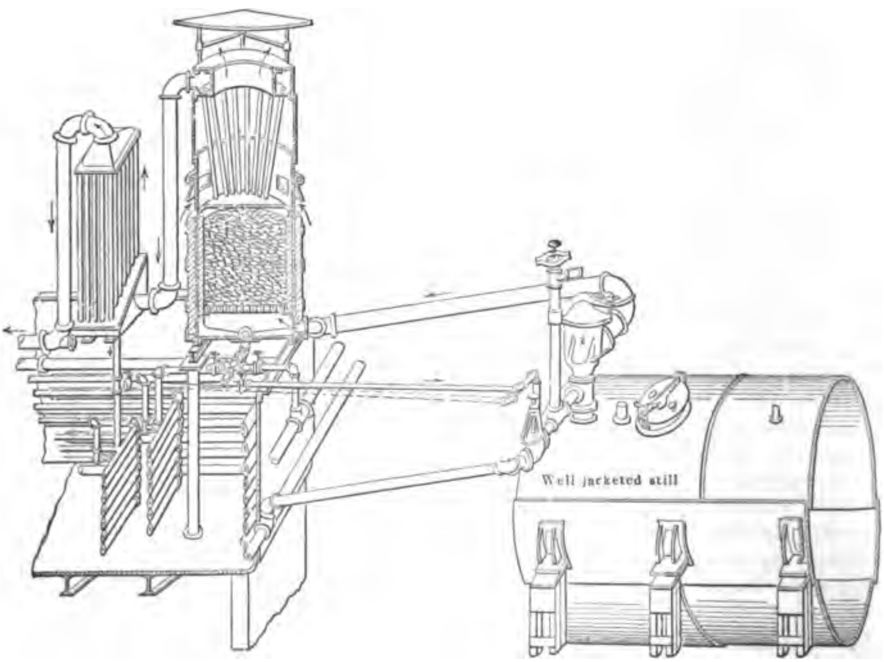
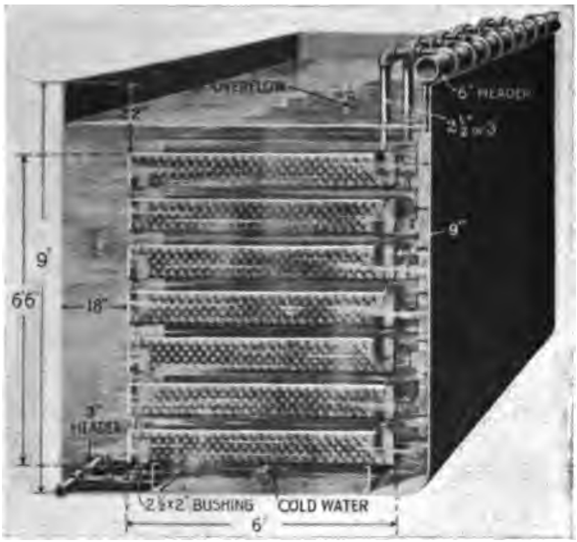


Fig. 104.—Perspective longitudinal elevation and section Van Dyke tower still.

holes underneath each baffle, and out through the laterals to the 12-inch main header. The liquid residue drops to the bottom and leaves the evaporator through an 8-inch line, there being a perforated steam coil in the bottom. Situated in the main vapor line



Condensing tank with stacks of Vento sections showing connections and course of the vapor through the pipes and stacks.

Cut-away view shows generous interior space and large surface exposed to cooling effect.

FIG. 105.—Vento condensing sections.

in front of the evaporator is an oil catcher, 3 feet in diameter by 4 feet high, filled with grooved and slotted vertical baffles. Liquid particles carried by the vapors fall to the bottom after striking these baffles, and are returned to the evaporator by a 1½-inch line. From the evaporator, the vapors pass to a series of dephlegmating towers, later described under this heading. The liquid residuum, it will be recollected,

leaves the evaporator from the bottom, whence it is run through an exchanger to the storage tanks.

As a typical tower still, the Van Dyke,[1] developed by the Standard Oil Company and illustrated in perspective longitudinal elevation and section in Fig. 104, is cited as an example. It will be noted that this apparatus comprises a well-jacketed conventional still, which is built ordinarily 14 feet in diameter by 40 feet long of sufficiently heavy plate to allow coking; a "heavy" tower, in which a portion of the gas-oil vapors and all of the paraffin distillate are condensed, and an "intermediate" tower, in which lighter gas-oil vapor and part of the kerosene fractions are reduced to a liquid state; and finally a light worm connected to a standard coil and arranged to condense the lighter kerosene and benzine fractions delivered from the top of the "intermediate" tower.

Many other forms of continuous and tower stills are successfully employed in various refineries, but they cannot be covered in the space allotted to this subject.

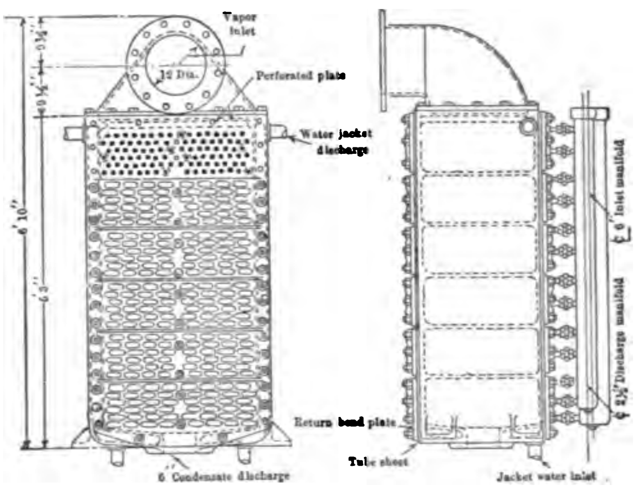


FIG. 106.—MacCamy condenser.

Condensers.—Of the special types of condensers employed in refinery practice, the Vento[2] section illustrated in Fig. 105, page 215, is claimed to be 15 per cent to 25 per cent more effective than the standard cast-iron worm. Condenser-coil data for this type of apparatus have already been included in the previous section.[3] This type of condenser comprises a series of narrow-passage, cored, cast-iron sections, designed to give intimate contact of vapors with the surrounding cooling water. Its principle of operation is apparent from the illustrations given.

Another form of special condenser which affords large cooling surface in small space is the MacCamy[4] condenser. Its method of construction and principle of operation are apparent without further comment, from the detailed drawing in Fig. 106.

One of the earlier forms of a self-contained tubular condenser is that of W. T.

[1] For further information in regard to this type of tower still, the reader is referred to U. S. Patents Nos. 1,095,438 and 1,143,466.

[2] Manufactured by the American Radiator Company, Chicago, Ill.

[3] See p. 164.

[4] Manufactured by the Southwestern Condensing Company, Los Angeles, Calif.

Leman [1] illustrated in detail in Fig. 107. From this it will be noted that water is forced to take a zigzag counter-current course to the flow of the vapor. This type of apparatus has been installed with considerable success in several refineries where condensing water is at a premium.

An improvement on the above principle is the Multiwhirl [2] condenser shown in detail in Fig. 108, page 218, which operates with the vapors entering the tubes at the

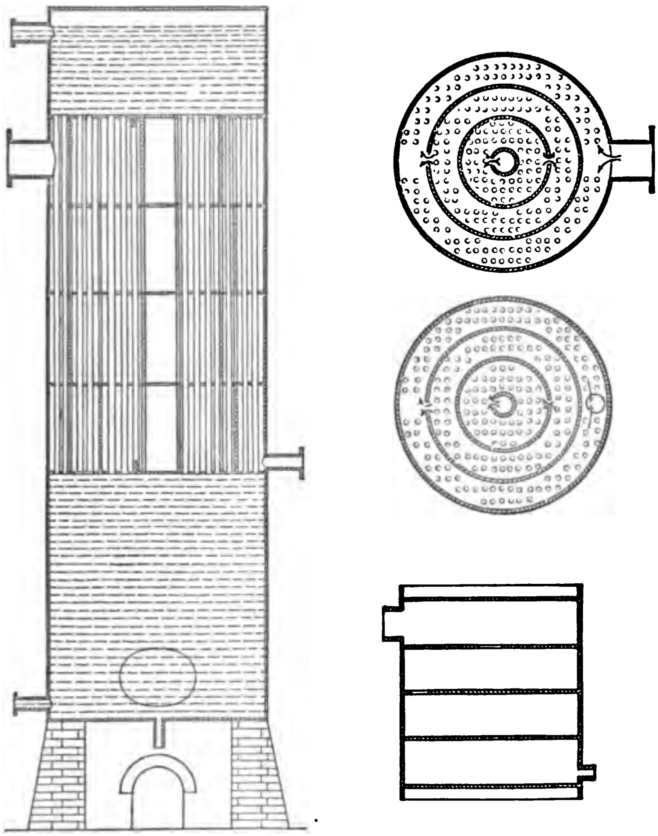


Fig. 107.—A Leman condenser.

top, and meeting a swirling counter-current of water admitted to the jacket at the bottom.

The condensers employed in the Trumble installation for the gasoline vapors are somewhat on the order of the Leman type, 48 inches in diameter, open top with one hundred and seventy-eight 2-inch by 18-foot tubes with a mean cooling surface of 1580 square feet per condenser. The distillate condensers in this plant, eight in number, are 30 inches in diameter, open top, sixty-nine 2-inch by 18-foot tubes, with a mean cooling surface of 1619 square feet. The illustration in Fig. 109, page 218, gives an idea of their appearance together with horizontal distillate coolers.

[1] See U. S. Patent No. 727,391, for further details of operation.

[2] Manufactured by the Griscom-Russell Company, New York, N. Y.

FIG. 108.—A multi-whirl condenser.

Still another form of condenser is the drop-out box, in which only the condensation of steam is attempted, the vapors to the same being bled from the upper coils of a standard type of condenser where the oil fractions have been cooled sufficiently to attain a liquid condition, but where steam still exists. This type of apparatus allows the withdrawal of water from the system at high temperature for return to the boilers, with consequent saving of heat, at the same time relieving the main worm of its additional condensation duty.

Condensers in which oil is used as a cooling medium, receiving heat from the hot vapors to save fuel, i.e., vapor-exchanging condensers, or simply vapor exchangers, have been developed to a considerable extent abroad and in the Trumble system in this country. On account of hitherto cheap fuel, and early designs which gave trouble from leakage and resulted in the contamination of the distillates and often in serious fires, this type of exchanger has hitherto made little general progress in this country. With the perfection now attained in welding, there seems to be no reason why such a type of exchanger should not come into more general use, although great care will have to be exercised in construction and design. Such a form of vapor exchanger, in which the condenser box takes the shape of a still, from which vapors may be evolved with safety in case the initial boiling point of the cooling oil is attained, is now being installed by a progressive refinery in the Middle West, with every prospect of operating success.

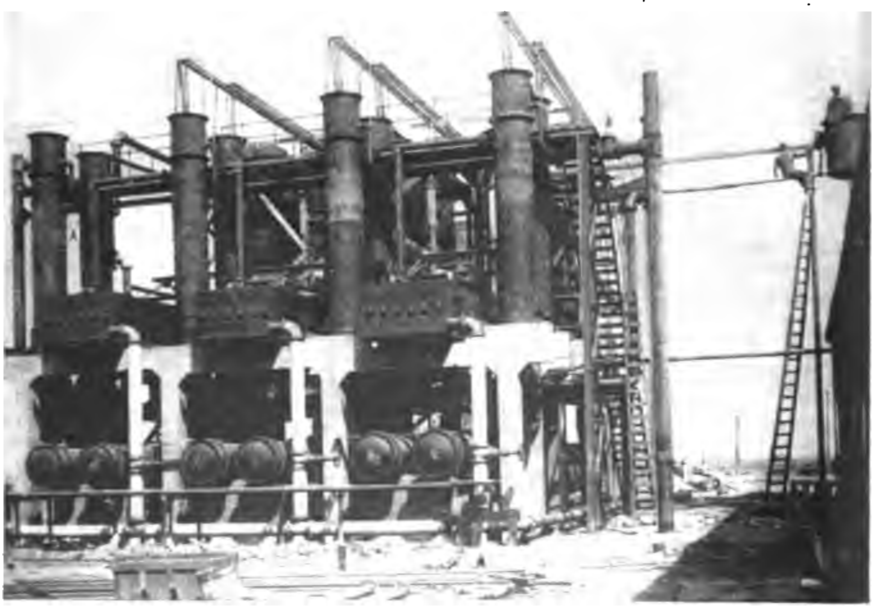


FIG. 109.—Fractionating columns and vertical condensers, Trumble plant number 1, at Woodriver, Illinois.

Towers.—Of the almost innumerable separating and dephlegmating towers employed in the various plants, special mention is made of those used in connection with the Trumble process. These units, arranged in a series of eight for each installa-

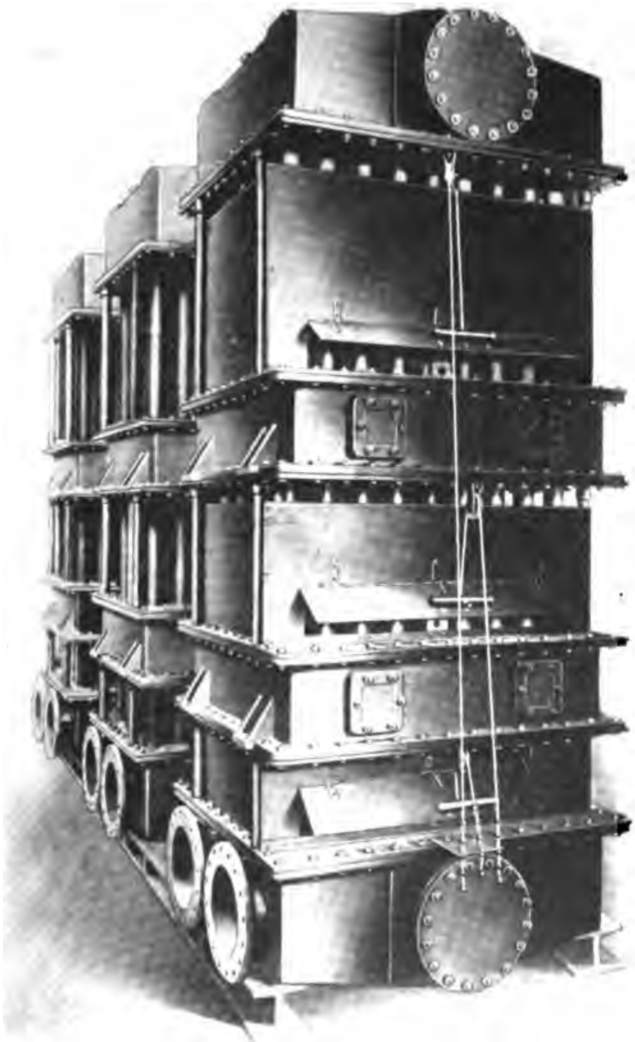


Fig. 110.—Gray towers.

tion, are connected from the evaporator and to each other by 12-inch vapor lines. Each dephlegmator is 6 feet wide by 16 to 18 feet high, and contains 18 plates. Half of the plates are 6 feet wide with a 2-foot central opening, the other half 5 feet wide without opening. They are arranged alternately with and without openings. Each

dephlegmator is equipped with a perforated steam coil at the bottom, and a cooling coil at the top arranged for the direct injection of cool distillate. The cooling is regulated by adjusting the speed of the pump or the temperature of the condensate.

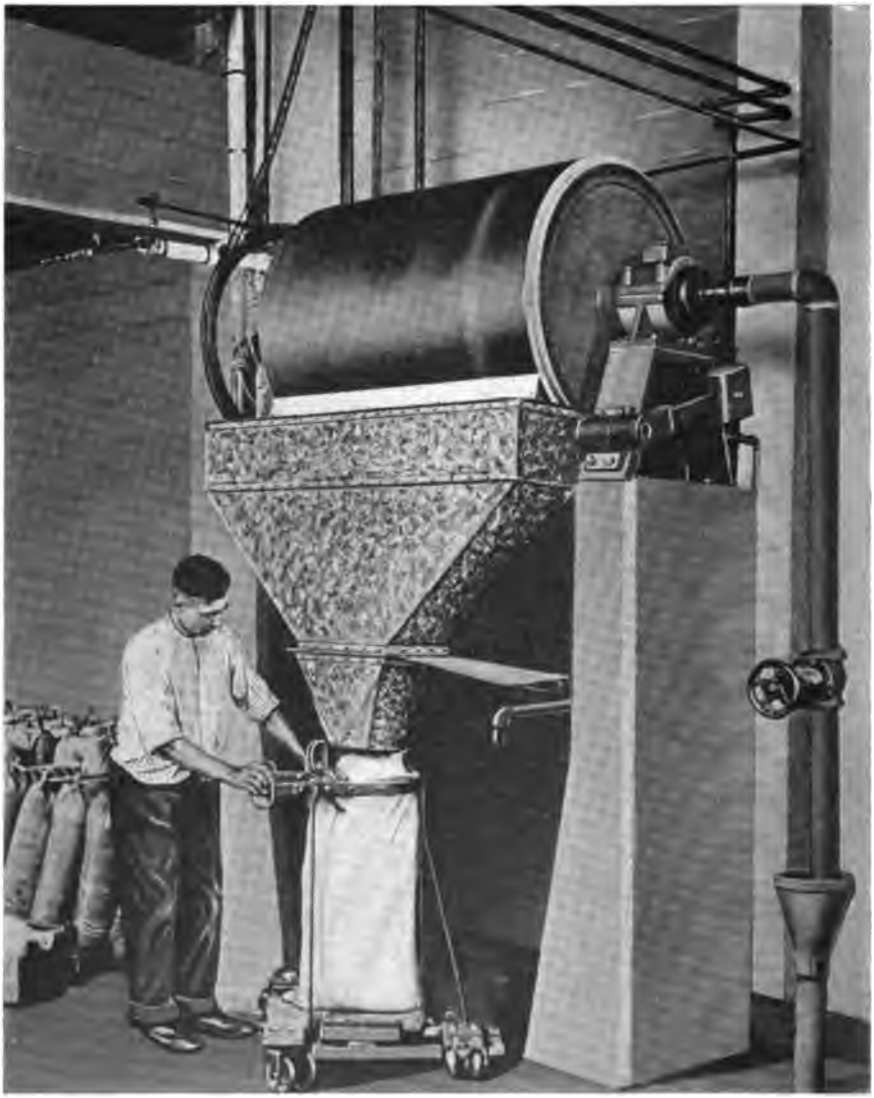


FIG. 111.—A wax-chipping machine.

By reference to Fig. 104, it will be noted that the "heavy" tower of the Van Dyke towers still comprises a bottom cylindrical drum provided with an entering vapor line, a bottom outlet for condensed distillate, and a false bottom or grating on which may be placed a special packing to increase dephlegmation. Expanded to the

top sheet of the bottom drum are a series of tubes for the passage of vapor. These in turn are joined to an annular drum from whence the uncondensed vapors pass to the second or intermediate tower. Condensation in the heavy tower is regulated by an outer jacket provided with draft doors. The second or intermediate tower comprises

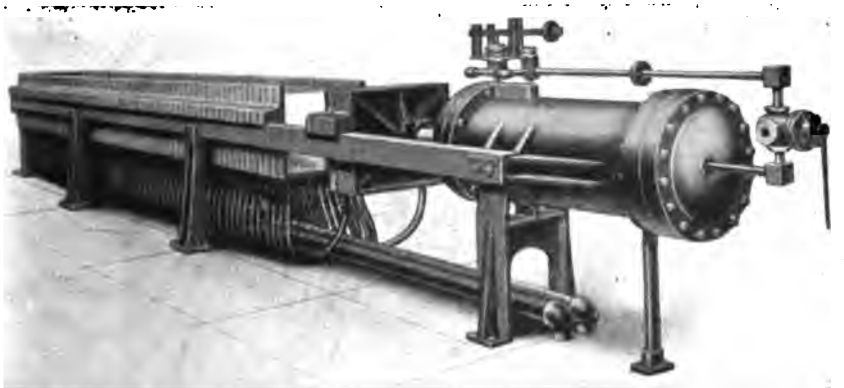


FIG. 112.—A Gray wax-molding press.

a series of air-cooled tubes which are expanded to a lower and upper vapor drum, the vapor passing through the tubes. The condensate leaves the lower drum by an outlet flange at the lowest point, and the uncondensed fractions leave at the top to be condensed in the usual manner.

The Gray system of dephlegmating towers, used principally in connection with

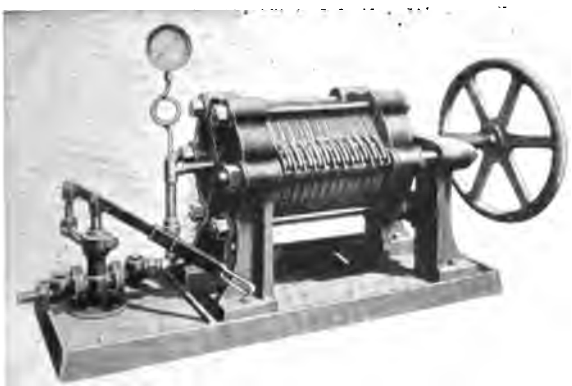


FIG. 113.—An experimental wax press.

lubricating oil stills is shown in Fig. 110, page 219. The method of operation is apparent from the cut and foregoing description, but further details as to yields obtained and cost of operation are given in a subsequent section.

Agitators.—Agitators are termed washers, abroad, where they are usually supported on a structural steel frame. Otherwise there is little departure from the conventional designs already discussed. A few refineries in this country, however, em-

ploy a closed system for continuous treating by which acid is introduced in counter-current to the distillate. The process is entirely successful in light oils, and is described at some length in a later section.[1] Another special form of agitator is employed for treating with sulphuric anhydride those distillates which contain aromatics. The details of the apparatus are not within the scope of this volume.

Wax-plant equipment.—Under special apparatus (although very generally employed in plants which barrel wax or ship it in sacks), is included the wax-cooling or chipping

Fig. 114.—An oil- and moisture-testing press.

machine, illustrated in Fig. 111, page 220. This apparatus comprises a hollow cast-iron drum, turned true on the outer cylindrical face, about 3 feet in diameter by 6 feet long, the exact size depending on plant capacity. The drum is arranged to rotate slowly in a horizontal plane on hollow-shaft bearings, through which cooling water flows. The drum is further mounted above a shallow pan, at such a height as to dip about one-half an inch into the melted wax contained in the latter, and is also provided with a knife scraper which removes the film of semi-solid wax which is produced during rotation by the cooling action of the water. The whole apparatus is

[1] See page 369.

installed in a somewhat elevated position, i.e., about 8 feet above the floor. The knife mentioned removes the wax in a continuous sheet from the drum, from which it falls through a guiding chute to barrels or sacks below.

In place of bulk shipments, many plants prepare wax in cakes for market. The former slow and unsatisfactory method of casting in pans which produced cakes lacking in uniformity in size and weight has been generally superseded by the wax-molding

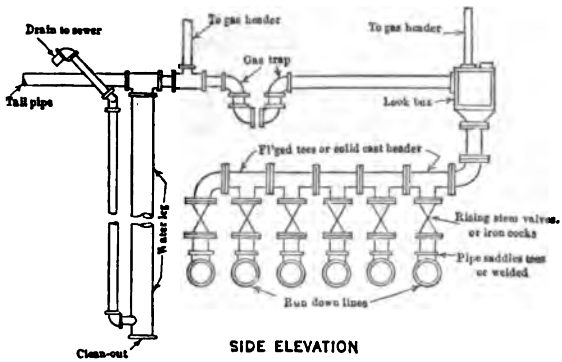


Fig. 115.—Standard receiving-house manifold.

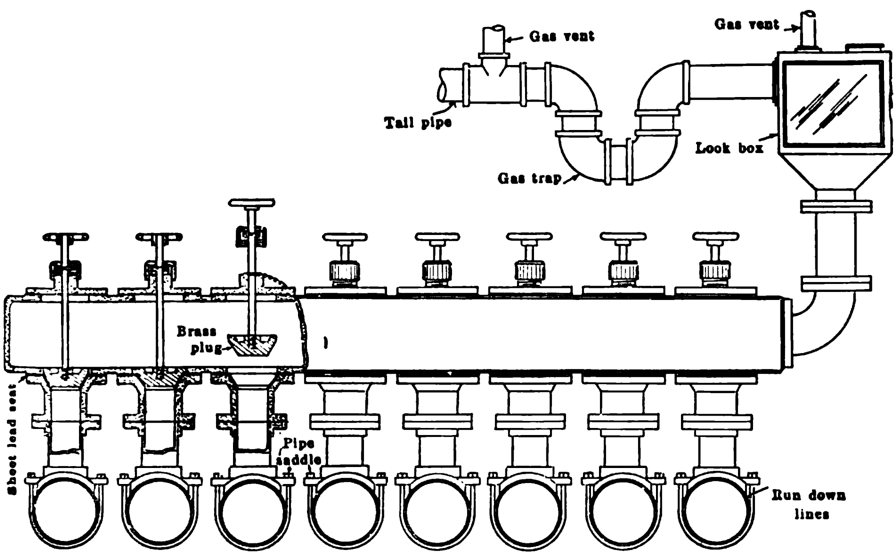


Fig. 116.—Details of a receiving-house manifold.

press, illustrated in Fig. 112, page 221. This apparatus resembles the ordinary soft-wax press, in which rings and plates have been replaced by molds and chilling sections. The sides of the latter extend 3 inches above the top, so that when the press is set up an open communicating channel is formed along the entire top and allows the wax to flow into every mold. Heavy galvanized iron is used in construction to prevent corrosion and to maintain wax free from specks, iron rust, etc. The molds are further arranged to cast two cakes in one filling.

Other forms of special wax-plant apparatus include the following: first, the experimental press, illustrated in Fig. 113, page 221, a duplicate in miniature of the large-sized standard unit, making it possible to check the process; and second, the oil- and moisture-testing press shown in Fig. 114, page 222, which is used for determining the percentage of oil and moisture in scale and finished wax, and which aids in checking the degree of "sweating" and determines the grade of the finished product. The details of the method of operation of this press are described in the chapter devoted to testing methods.

Distributing equipment.—This subject may be roughly divided into the following headings: (*a*) manifolds, special valves, racks, fillers, etc., used to control intermediates and distribute finished products to the various containers known to the trade; (*b*) special machinery used in the manufacture and preparation of the latter, i.e.,

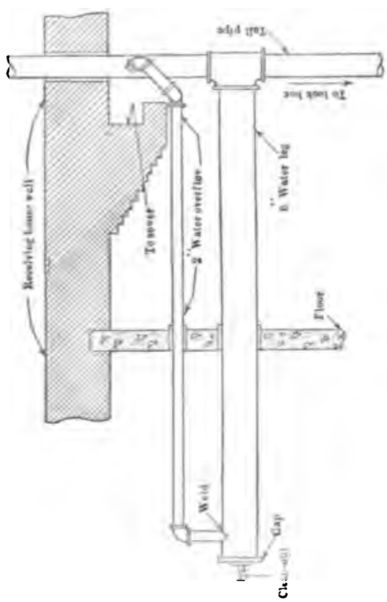


Fig. 117.—A water separator.

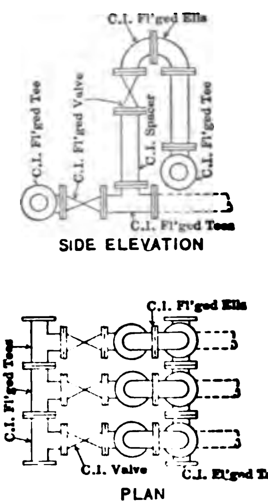


Fig. 118.—Standard pump-house manifolds.

cans, drum, barrels, etc.; and (*c*) nailing machines, carrier devices, etc., for the final handling of finished package goods.

With reference to "*a*," the first distribution of refinery products is effected by the receiving house manifold, shown in Fig. 115, page 223. The details of another type, intended for corrosive sulphur-bearing distillates, appear in Fig. 116, their method of operation being readily understood from the cuts, without further comment. A valveless manifold, where the oil from the condenser flows into a shallow cylindrical drum about 24 inches in diameter by 6 inches high, which is provided with a discharge spout and arranged to rotate on a vertical axis, discharging a stream into the compartment desired, has also been introduced with more or less success. However, the old standard type continues to find most favor. The separation of water from the various overhead distillates is generally accomplished by the introduction of a water separator in the run-down line just prior to its entrance to the look-box of the manifold. The prin-

ciple of its operation will be readily apparent from the illustration in Fig. 117. Two types of pump-house manifolds, which allow connecting lines to be used for either suction or discharge as may be desired, are shown in detail in Fig. 118, and are self-explanatory.

For distribution to tank cars, the loading rack is used. The construction varies from a short wooden trestle, capable of loading two or three cars from one side of the

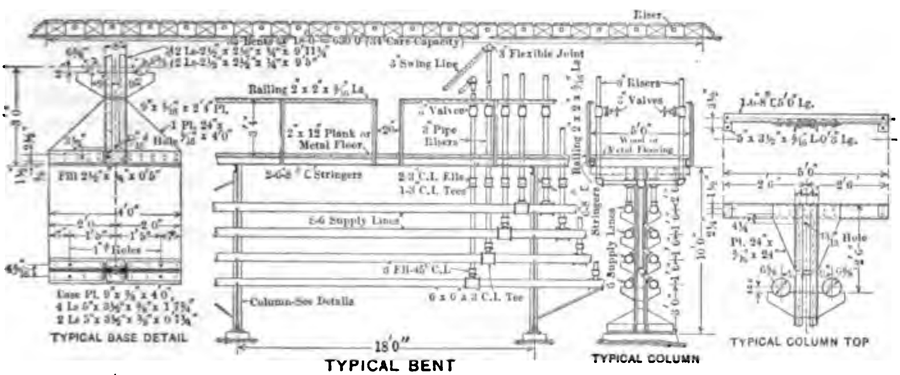


FIG. 119.—Side and sectional elevation loading rack, showing lines in position.

rack only, to a structural steel frame rack, many hundred feet in length and capable of spotting twenty-five to fifty cars or more on each side. The details of such a steel frame rack are shown in Fig. 119. It should be noted that the loading lines are supported. on either side of the column supports by suitable brackets. Other forms of design maintain lines in positions varying from the ground to location on an elevated bracket above a walkway, each refiner having his own ideas on this subject.

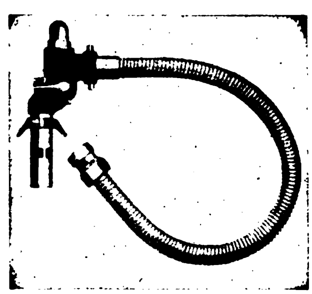


FIG. 120.—A pen-flex barrel filler.

Barrels and drums are generally filled with the aid of automatic fillers attached to a flexible metallic hose. Various types are on the market, there usually being a slight difference in construction between the fillers intended for gasoline and those for other petroleum products. A type in quite general use is illustrated in Fig. 120. Cans are also automatically filled, several types of machines for this purpose being available. The illustration in Fig. 121, page 226, shows a well-known five-gallon can-filling machine. Such a machine will automatically measure and fill 6000 cans per day of ten hours, and requires three men and a boy for operation. The cans are placed, filled, capped, and soldered during the intervals between the rotation of the carriage.

With respect to "b," many of the larger refineries manufacture their own cans, drums, barrels, etc., while practically all the firms who ship in wooden barrels, at least recooper this class of package. Therefore, a brief description of the special machinery employed will not be out of place. The 5-gallon can selected as typical of the industry is made from three "blanks"; two sheets of which, the " body blanks," form the four sides, and the third sheet the two ends. A trimming press cuts the body blanks to the

exact size, and a hemming press turns over the top and bottom edges. A paneling and bending press now stamps the panels, hooks, etc., and bends the body at right angles. Such a press has a capacity of 7000 blanks daily when operated by an experienced pressman. Two bent body blanks are united by a horning press to form the complete body, which securely locks the vertical body seams one at a time. The heads, which in the meantime have been stamped and embossed in a suitable press, are now attached to the bodies by a "squeezer," from which the cans pass to a seam-rolling machine. Such machines have a capacity of 9000 to 12,000 five-gallon cans in ten hours and effect a large saving in solder. Handles, caps, etc., are also made and attached by special machines. The soldering is done by certain patented processes involving a continuous movement of cans, by which the seams are automatically presented in succession to a thin heating flame, flux dip, solder bath, and the action of a cleansing brush to remove the excess of solder. The entire series of soldering operations, including the turning of the cans to present the various seams, is accomplished by the one machine.

Steel drums are made on somewhat similar lines, rolls naturally replacing presses

FIG. 121.—A Bliss five-gallon can-filling machine.

in part, and rivets and brazing being substituted for solder. The bilged steel barrel is made by first forming a cylindrical open-top drum by riveting and brazing the side seam, followed by rolling on the bottom head and brazing the chime. The drum is now placed in a steel die whose inner surface conforms to the shape of the finished barrel. It is then filled with water and closed with a tight-fitting top, and the die is locked. Hydraulic pressure is applied to the water in the drum, causing the steel of the latter to flow cold, and take the shape of the die. This forms a perfect bilged barrel, which is now completed by rolling on the top head and brazing the seam.

In the manufacture of wooden barrels, staves are received in blank or jointed. The latter operation is effected by a stave jointer, which consists of a rapidly revolving vertical disk, in which are inserted jointing knives which surface the edge of the staves at proper bevel and taper to make a tight joint when formed into a finished barrel. The equalized jointed staves are placed by hand in a setting-up form, in sufficient number to fit tightly, and are held in place by a temporary truss hoop. After this, the partially formed barrel with the staves held together at one end and separated at the other, goes first through a steaming process to render the staves pliable, and then to a windlass, where the open, separated ends are drawn together and the bilge

formed. A second truss hoop is now thrown over the ends that are brought together by the windlass, and the shell is placed over a special gas- or oil-fired stove, from which it is removed just before charring takes place. The shell next goes in succession to the trusser, where the staves are more firmly brought together; to the crozer, where trimming, chamfering, crozing, and howeling are accomplished in one operation; and lastly to the barrel lathe, where a smooth outer surface is produced. The heads, which in the meantime have been made in a head rounder, are now inserted. The chimes are then flagged, and the hoops driven by a hoop-driving machine. The barrel is now ready for sizing. In refineries where only recoopering is done, broken or defective staves are usually replaced by others from a knocked-down barrel. Any necessary jointing is accomplished by a long fixed jointing plane over which each stave is passed to effect its reduction to the proper size. The necessary crozing is done by hand tools and the heading is purchased already made. The principal part of recoopering therefore consists in flagging and hoop-driving, with occasional replacements of broken staves, defective heads, etc. Before a second-hand barrel is recoopered, it must first be steamed; if it is very dirty, one head must be withdrawn, and the inner surface scraped and cleaned. The barrel-washing machine serves admirably for this purpose, and an adaptation of the same has also been developed for painting.

In regard to "*c*," many of the larger plants, especially in connection with the 5-gallon export cans, have box-making machines, which automatically nail and case two 5-gallon cans to a package, with very little attention. Endless carriers transport the finished boxes or barrels to the steamers or cars, and gravity "lowerators," working automatically, pass the merchandise to lower levels.

V. GENERAL CONSTRUCTION AND EQUIPMENT

In actual refinery construction, especially in a plant of large size, erection should proceed in an orderly and systematic manner, so that delays in the work will be reduced to a minimum and each unit be completed as needed. This obviously requires great attention to detail in ordering and routing the material, equipment, etc., and the planning of simultaneous construction of many different groups, such as buildings, stills, tanks, etc. While it is evident that no general rule can apply for all conditions, as the difficulties of receiving material on exact schedule, and the delays incident to the scarcity of labor, strikes, etc., are well recognized, the following typical systematized scheme of construction is suggested, as it has been tried out and found practical. Of course, the local conditions, the size of the projected plant, and the question of whether construction is to be done wholly or in part by outside contractors, will modify each individual case; but the principle involved will remain unaltered.

Systematic Scheme of Construction for a Complete Refinery

Order of Operations

1. Contour survey of site.
2. Location of units.
3. Extension of railroad construction spur.
4. Erection of temporary buildings.
    a. Engineer's office.
    b. Contractor's offices and tool shanties.
    c. Repair shop and store-sheds.
    d. Commissary and bunk houses.
5. General simultaneous construction in the following order, of:

Buildings, equipment, etc.:
- *a.* Supply storehouse.
- *b.* Carpenter, pipe and machine shop.
- *c.* Boiler and power houses.
- *d.* Pump houses.
- *e.* Receiving houses.
- *f.* Laboratory.
- *g.* Office.
- *h.* Wax plant.
- *i.* Filter plant.
- *j.* Shipping and cooperage buildings
- *k.* Car-repair shop.

Stills, condensers, etc.:
- *a.* Crude stills, condensers, etc.
- *b.* Rerunning stills, condensers, etc.
- *c.* Steam stills, condensers, etc.
- *d.* Lubricating stills, condensers, etc.
- *e.* Pressure stills, condensers, etc.
- *f.* Fire-walls.

Tanks, agitators, etc.:
- *a.* Crude tanks.
- *b.* Run-down tanks.
- *c.* Working tanks.
- *d.* Light-oil agitators.
- *e.* Bleachers.
- *f.* Storage tanks.
- *g.* Lubricating-oil agitators.
- *h.* Lubricating-oil tanks.
- *i.* Fire-dikes.

Miscellaneous:
- *a.* Water - supply system, lines, etc.
- *b.* Bunkering wharf, pipe-line, etc.
- *c.* Oil, gas, and steam connecting lines.
- *d.* Traps and sewers.
- *e.* Foam system.
- *f.* Fence, walks, final grading.

The contour survey of the site, the location of various units, and the extension of a railroad spur have already been discussed in the section on general plant design.

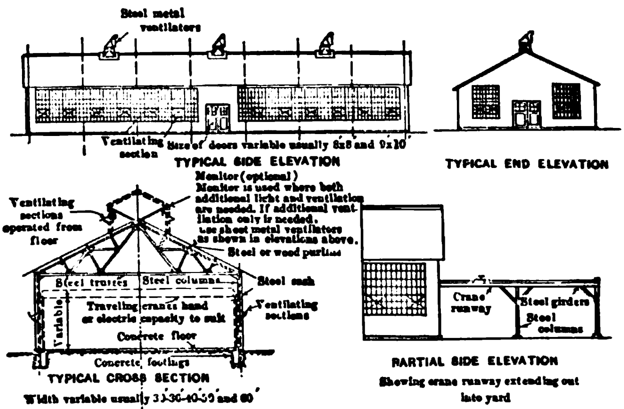


FIG. 122.—Elevations and cross section of a typical Austin standard building.

The nature of the temporary buildings mentioned is self-evident to anyone familiar with general construction.

Passing to permanent refinery structures, a good substantial storehouse should be one of the first buildings erected and should be closely followed by the pipe and machine shop. The standard factory buildings offered to the trade are admirably adapted to these purposes. Such buildings, illustrated in Fig. 122, may be bought in steel frame construction, for immediate shipment from stock, in variable widths of 30, 36, 40, 50, and 60 feet in multiple lengths of 20 feet, thus meeting practically any requirement. Windows and doors may be arranged to suit, the frames covered with asbestos protected metal, galvanized steel, or black iron as may be desired. Even brick walls can be installed where it is deemed necessary. Asbestos-protected metal is recommended for the buildings under consideration. Early storehouse erection will soon repay its cost in saving material and supplies from loss by mislaying, theft, and rust. A pipe and machine shop is an almost immediate necessity from the moment the steel assembly begins, the power for operation being obtained from some temporary source until the completion of the steam plant or other primal energy unit. The size of these buildings will obviously depend on the capacity of the plant, the nearness to supplies, the completeness of machine-shop equipment, etc. For example a certain

5000-barrel plant which includes refining to lubricants and which is two days away from supplies, finds a storehouse 30 by 60 feet, and a pipe and machine shop 50 by 60 feet adequate to its needs. The latter, in fact, is of sufficient size to allow the partitioning of one end into a blacksmith shop and a carpenter shop. In larger plants these shops would be more efficient as detached units.

As soon as possible after the foundations for the warehouse and shops have been started, the work on boiler- and power-house foundations should begin. Here again, the standard ready-made building can be used to advantage. In determining the size of the building, some consideration should be given to climatic conditions, for a congested, ill-ventilated boiler house in the warmer latitudes, especially in large plants,

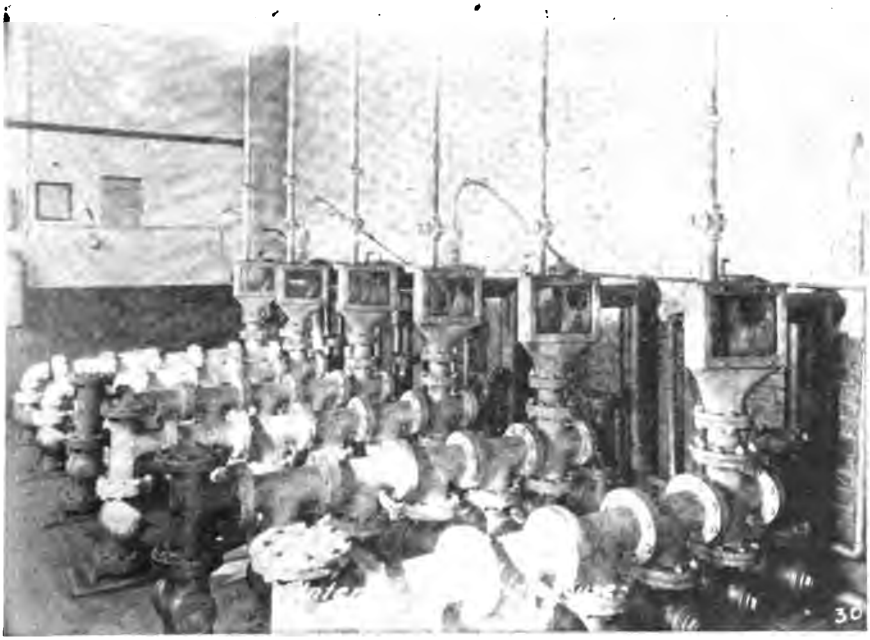


FIG. 123.—Interior receiving house.

means poor operating efficiency. In general it is also advisable to delay the erection of the building proper until the boilers themselves have been hung in supporting frames.

On account of the inflammable nature of the products handled, and the proximity of the receiving houses to the stills, both the pump houses and the units last named should be preferably of brick construction, with concrete roofs, doorways and windows fitted with metal-sheathed self-closing doors and shutters and provided with fusible links to release in case of fire. In other words, fireproof construction should be used throughout. The size of such buildings will, of course, depend on the number and type of the pumps installed in the one case, and the number of entering run-down lines in the other. In the pump-house design, sufficient room should always be left to allow the withdrawal of the pump pistons. It should further be noted that distributing manifolds will often require proportionately more room than the pumps themselves. A safe procedure for

determining the length of the receiving houses is to space run-down manifolds on 3-foot 6-inch centers, with equal intervals at the ends of the building. The width of the latter should be governed by the number of proposed run-down lines, it being always advisable to make allowance for future additions. In the actual erection of these buildings, the rear walls should not proceed until the entering lines have been connected to the manifolds or apertures left for such connections. The interior of a typical recovery house is illustrated in Fig. 123.

Where the plant is likely to begin shipping as a stripping plant upon the completion

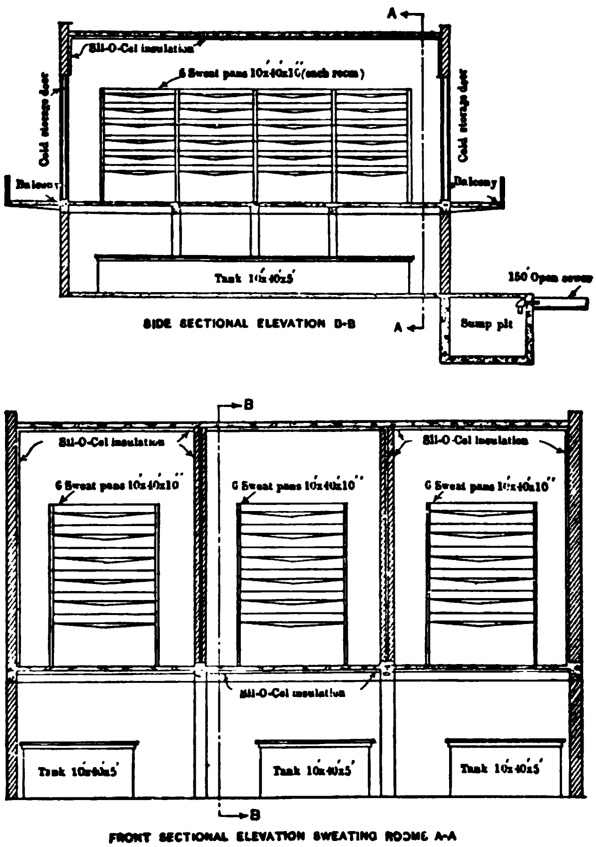


FIG. 124.—Sectional side and end elevation of a three-oven sweating building.

of the crude still battery, the laboratory foundations should be started immediately after the receiving house. For similar reasons the refinery office building may be begun about this time, but this depends a great deal on the size of the building required, the nature of the engineer's temporary quarters, and the amount of work being done by the refinery office force. It would be poor economy to attempt a systematic checking of material receipts, to follow up the system of shipments and record of actual construction cost with an office force working under disadvantages. In fact under certain conditions, an office building should be one of the first units constructed at the plant. Where a plant is so situated that the housing problem is a feature of the construction, attention

should be given at this time to permanent dwelling cottages, as these should be in readiness for the process men when the actual operation begins.

While the erection of the laboratory or the office is in progress, foundations should

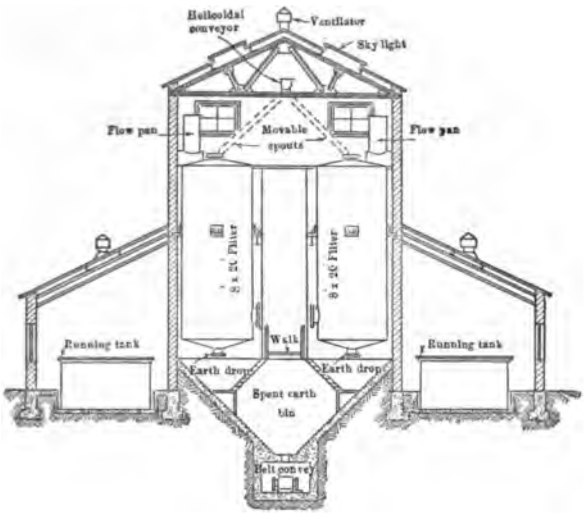
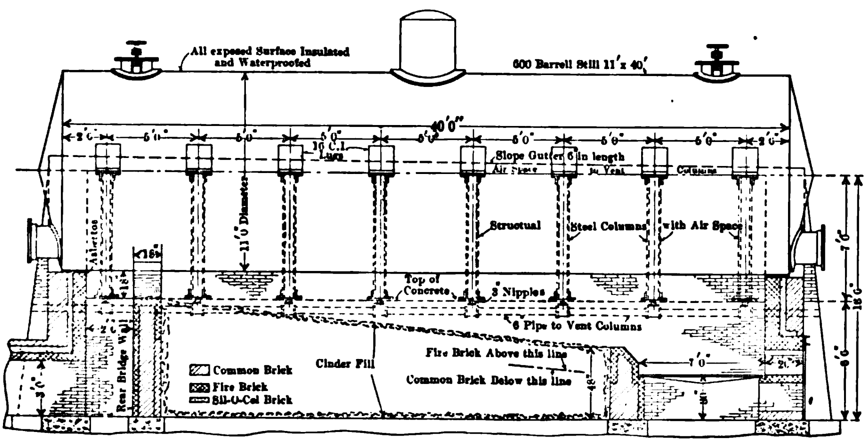


FIG. 125.—Sectional elevation of a filter house.

be cast for the wax-plant buildings followed by those of the filter-house units. These buildings, obviously of special design, should be of heavy substantial construction, and the laying of the walls should be retarded until the heavier equipment is



Longitudinal section of brickwork on center line of still.

FIG. 126.—Setting for end-fired stills, side elevation.

installed. The floor plan and elevation of a 125-ton wax plant has already been included in the section on general apparatus. Fig. 124 shows a sectional elevation of a sweater building, in which it will be noted that the " oven " walls are specially constructed

with a central course of insulating brick. A typical filter house is given in vertical cross section in Fig. 125.

Shipping and cooperage buildings may be adapted from previously mentioned standard buildings, but if they are to be more than one story high, special design is advisable. Fireproof construction should be used, of course, throughout. The size will naturally depend upon the amount of compounding, whether shipping is done by barrels or cans, and whether the latter are manufactured or prepared at the plant. The design is a matter of specialization and is beyond the scope of this volume.

The erection of a car-repair shop may be left to the last, unless it is also to be used as a boiler shop. This combination, which is advantageous in certain instances, necessitates the early completion of the shop if the fabrication of any plate work is to be attempted by the refinery during the general building of the plant. Here again, the standard building, complete with traveling crane, can be very profitably used. Several well-known plants have adopted this plan.

Simultaneously with the erection of the buildings should proceed the erection of

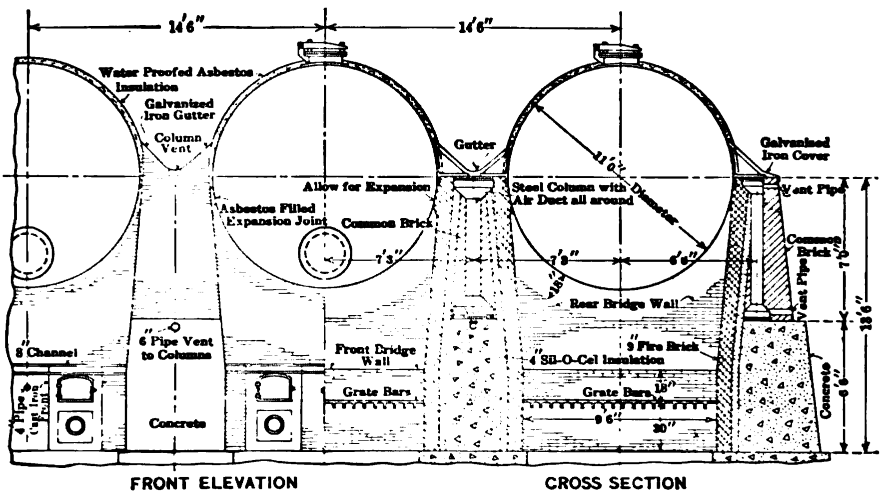


FIG. 127.—Setting for end-fired stills, end elevation.

the stills, condensers, etc. Standard still foundations are usually cast, if for end-fired units, in a battery of from four to twelve stills, six being a common number and twelve the maximum usually constructed in one block. A typical setting is shown in side and end elevation in Figs. 126 and 127. A variation of this form is the return side-flue modification. In this the flue gases, instead of leaving through an underground passage back of the bridge wall, pass through an uptake in the rear side walls, and return in contact with the lower upper shell surface, through a tile-covered side flue built over the lugs. The side flues, usually about 3 feet in height, are double between the stills and single on the end units of the battery, and terminate in metal stacks of 30- and 22-inch diameter respectively. The latter are provided with suitable draft dampers, and are erected at the ends of the flues, as close to the front of the still as good construction will permit. It is claimed that such a form of flue will effect a saving of 15 per cent in fuel, but is rather severe on the upper sheets. It is not now in general use. Side-fired stills are commonly erected in units of two, side firing in general being more suitable for coking, because the still bottoms receive a more uniform heat. The Van

Dyke patented setting is shown in Fig. 128. Vertical cylindrical stills of the cheese-box type are practically obsolete as crude stills, but are still used in a limited way as

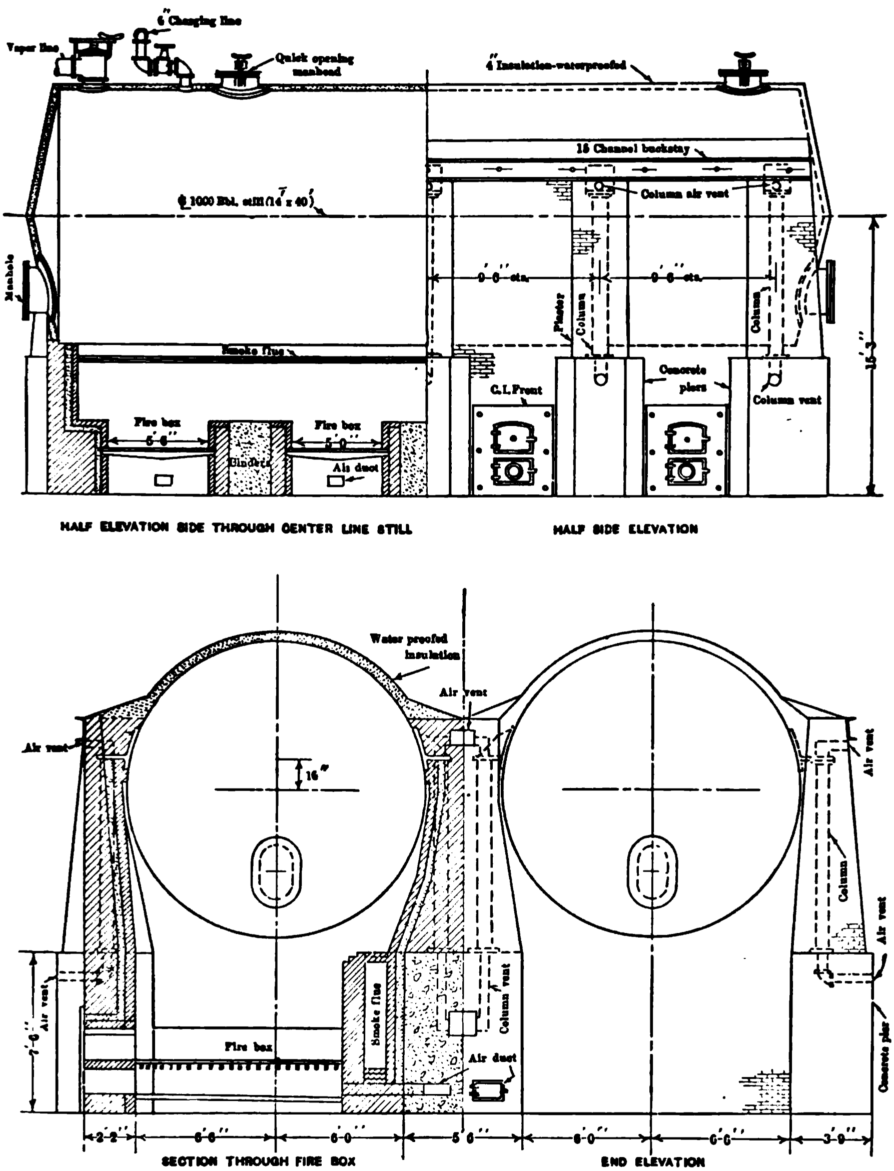


Fig. 128.—Side and end elevation of the setting of side-fired stills.

sweetening units. They are set in single form, Fig. 129 illustrating the type of setting employed.

Erection methods will vary, depending on the type of setting employed. A com-

mon practice is to erect the walls to a height about equal to the permanent level of the bottom of the still. I-beams or sill timbers are then placed thereon as tempor-

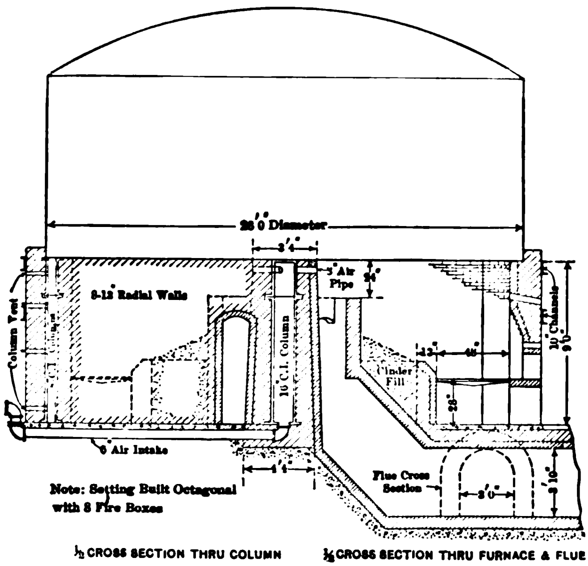


FIG. 129.—Setting for vertical cheese-box still, vertical cross section.

ary supports, to allow the fitting up and riveting of the shells, or the rolling into position of the finished stills made up in the shop. The maximum diameter of ready fabri-

FIG. 130.—Crude still supports, and foundations designed for mechanical stokers.

cated units is 11 feet, on account of railroad shipping regulations. As soon as the shells are complete or in position, the lugs or hanger straps are attached, the supporting

columns[1] erected, the stills let down on them or properly hung, the temporary supports withdrawn and the brickwork brought to completion. Such a method of erection is illustrated in Fig. 130, where it will be noted that the design is arranged for

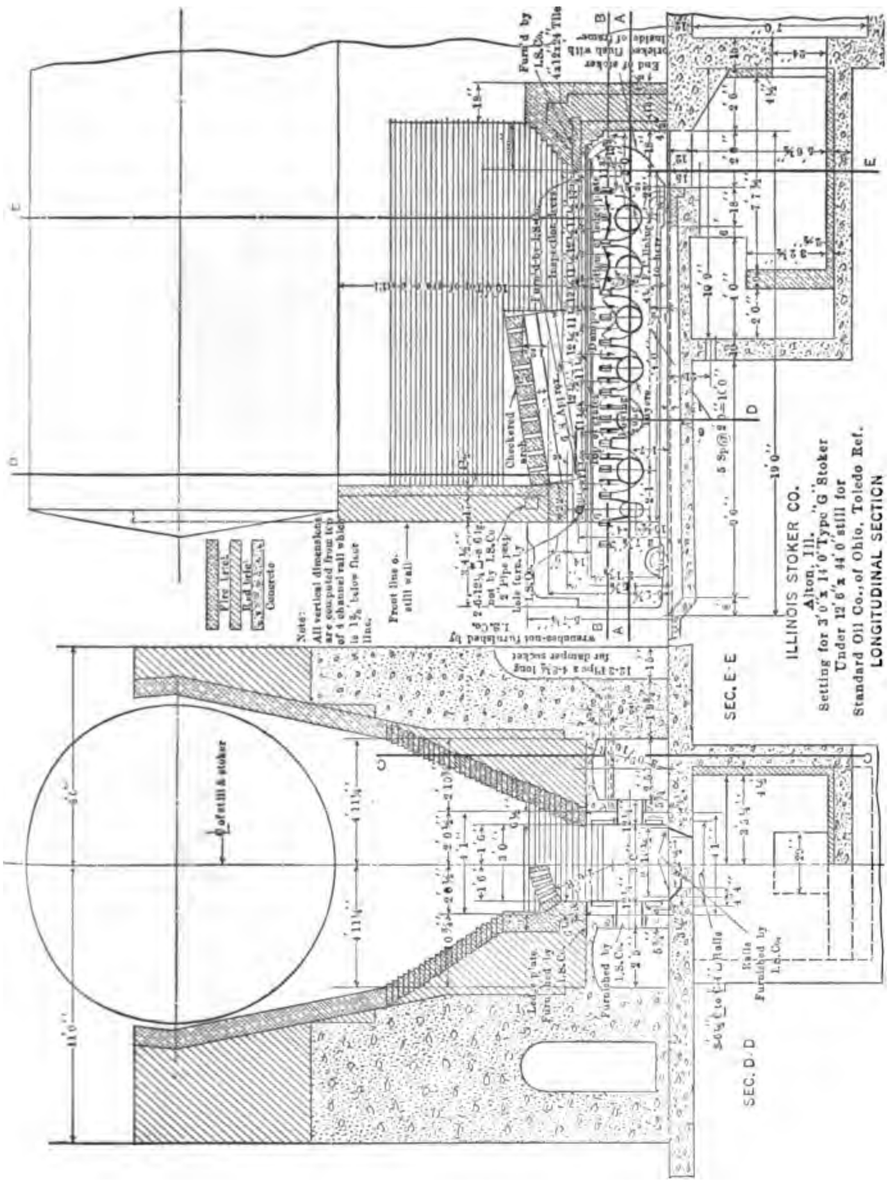


Fig. 131.—Longitudinal and vertical section of an Illinois mechanical stoker setting for 12 feet 6 inches diameter by 44-foot still.

mechanical-stoker firing. The detailed plan for a somewhat similar setting is shown in Fig. 131.

[1] Columns may be either of cast iron or structural steel. Modern practice, with its more efficient methods of heat-protective insulation and air-cooling flues giving preference to the steel units.

Where the suspension method is employed with columns extending to grade level, the stills are often fabricated at grade at the approximate final location or are rolled to such

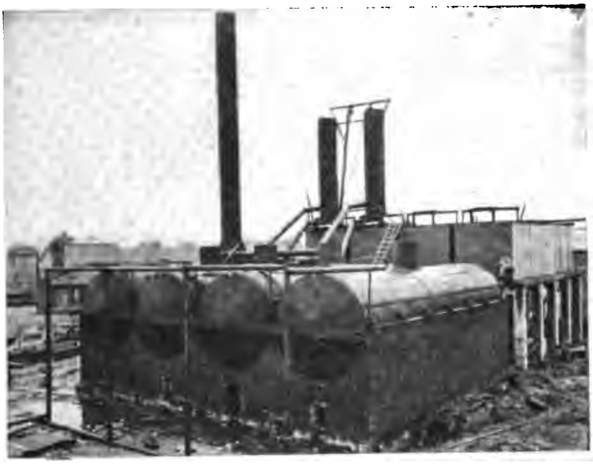


Fig. 132.—Battery stills on structural steel supports with steel-encased setting.

a position upon the completion of the shell. The columns and frames are then erected and the stills swung into place before the brickwork is begun. Such a form of setting

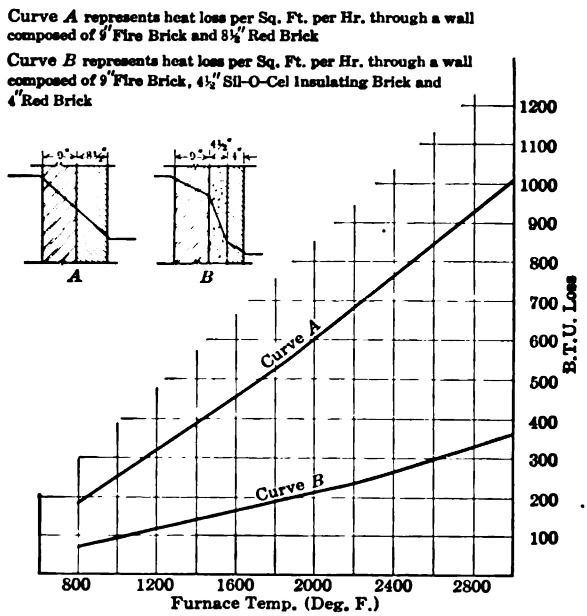


Fig. 133.—Comparison of heat losses through insulated and uninsulated walls.

has been previously shown in receding elevation in Fig. 57, page 151. A variation in the method of erection is to provide the still with lugs, supported by a structural

steel frame, and steel-encase the entire setting. This form of construction is illustrated in Fig. 132.

All foundations below grade should be of concrete, the depth varying with the nature of the soil, piling being used where it is necessary. It is also preferable to employ concrete for the upper supporting walls, provided it is protected from the action of heat by two courses of fire-brick and a 4½-inch thickness of silocel brick or other special insulating material. General practice is, however, to use common red brick rather than concrete, for the outer wall courses above the level of the bottom of the still and for the end walls. This is because such portions of the setting are more likely to require tearing out for the repairs incident to the replacement of bottom, side and lug sheets, etc. A comparison of heat losses through insulated and uninsulated walls is shown in Fig. 133. The need for special insulating material is at once apparent not only where concrete is employed but in every case of efficient installation. Reduced to tabular form, the fuel losses from uninsulated and insulated walls appear as follows:

Diagram Showing Heat Flow and Fuel Loss in Furnace Walls

Fuel Losses per Hour per 1000 Square Feet of Radiating Surface

Wall	Fuel	Loss per 1000 feet per hour, B.t.u.	Pounds of coal loss per 1000 feet	Gallons of oil loss per 1000 feet	Cubic feet gas loss per 1000 feet	Calorific value
Uninsulated	Coal	840,000	70	....	....	12,000 B.t.u. per pound
Insulated...	Coal	314,000	26	....	....	12,000 B.t.u. per pound
Uninsulated	Oil	840,000	....	5.8	....	145,000 B.t.u. per gallon
Insulated...	Oil	314,000	....	2.2	....	145,000 B.t.u. per gallon
Uninsulated	Gas	840,000	....	....	1400	600 B.t.u. per cubic foot
Insulated...	Gas	314,000	....	....	523	600 B.t.u. per cubic foot

The ends of the still, and the exposed portion of the shell above the lugs are commonly insulated by one of two methods. The first is securely to attach, by means of cable

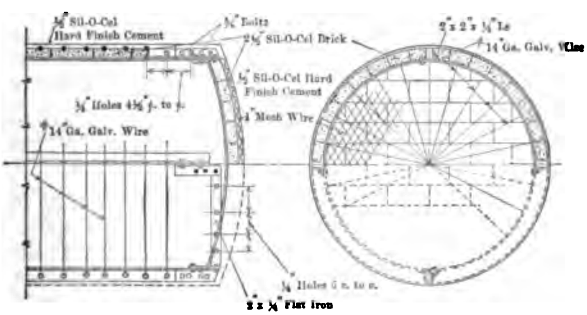


FIG. 134.—Method of protective insulation by application of blocks of non-conducting material.

wires, a covering of metal lath, over which is spread two or more coats of protective heat-insulating cement, with chicken-wire reinforcement between the layers, to a thickness of about 1½ inches, the whole being finally waterproofed with a special coating.

The second method is to apply insulating blocks, fastened with wires to cables or angles and finished with waterproof cement coating as in the first instance. This is illustrated in Fig. 134, page 237. It is claimed that a saving of 60 to 70 per cent in heat radiation may be effected by either of the methods described. Stills operating at low temperature, such as steam stills, may have the insulation further protected with a canvas covering, sewed or tacked on over the last coat of cement and made absolutely water-tight by several applications of standard paint. Steam still towers are preferably finished in such a manner.

The erection of tube stills, apart from variations in design, involves, in general, the construction of furnace foundations, special flues, and baffle passes. The walls should progress as the pipe coils are installed, the furnaces finally being capped with arch roofs,

a. Right-hand view of Bell retorts during construction; note prewarming coil.

b. Front and left-hand view of Bell-topping retort during construction.

FIG. 135.—Progress construction Bell-topping retorts.

and the entire structure reinforced with vertical I-beams or T-bars tied together with suitable rods provided with turnbuckles. The illustration in Fig. 135 gives a very clear idea of the erection procedure for this type of still.

Condensers are commonly supported by concrete or brick walls, on which are laid pipe or I-beam rafters of suitable weight at proper distances apart. Supports constructed entirely of structural steel are sometimes employed, but such construction is not recommended unless a concrete wall be erected next to the stills, and preferably one adjacent to the receiving house side as well, for fire protection. In this case it is very desirable that intermediate columns and rafters be of structural design. Aside from fire-risk considerations, the condenser support design is obviously a matter of the proper spacing of the walls and the selection of columns and rafters. This is dependent upon the total weight involved and is a readily solved but individual problem. Similarly the designs for the column, tower, and evaporator supports are evolved, these units

being usually constructed in the field directly on supports, when they are over six tons in weight, because of the difficulty in raising already fabricated apparatus of this nature to elevated positions. When the same are built up before being shipped it is preferable to erect them by the aid of two jin-poles fitted with blocks and tackle. The towers or columns are supported during erection at a point slightly above the center of gravity, so that the bottom may be swung into the desired position. Hand crabs may be employed where one or two units are to be raised, but a steam or electrically driven winch is a handy piece of apparatus for this purpose. and may also be very profitably employed in raising sections of the condenser coil or vapor line into position.

Coil supports should be of pipe or structural steel, particularly if the design calls for vertical members. The average life of wood is about four to six years in such service. Where the latter is employed, treated yellow pine or cypress should be chosen. Wood gives the best satisfaction when employed as horizontal blocks between wrought-iron manifold coils in small condensers.

While the construction of buildings and stills is proceeding, the necessary grading for tank sites should have been completed early, and the tank builders should be at work, in order that the crude tanks may be completed and in readiness to store crude if so desired. Run-down tanks should follow next, and be ready to hook up to run-down lines, as the latter are extended from the receiving houses. Other tanks, agitators, etc., should come next in the order previously specified although this order may be modified according to the needs and receipt of material. As a rule it is inadvisable to erect dikes or fire-walls in completion until all connections are made; but when grading, care should at least be taken that a " borrow " pit is not located on a dike circle and that wastage may be profitably dragged to the dike line. The preparation of a tank site usually requires little more than grading to a uniform level and providing a center stake for the erecting crew. On made-land or river-bottom soil, piling is occasionally necessary, but this may be generally avoided by the selection of tanks of large diameter. Ash fills should be covered with at least 6 feet of sand and should be well tamped before proceeding with erection. In general it is always advisable to paint the bottoms of the tanks with two coats of protective paint before lowering them from the horses. Certain by-products of the coal tar industry serve every purpose and are obtainable at a nominal price.

The erection equipment for the tanks is simplicity itself. It consists of a sufficient number of horses for supporting the bottoms under construction, one or two tripods for the erection of the first two rings, a jin-pole for the upper courses, and a stage provided with grooved-sheave pulleys, which may be hung from the upper sheets and moved around the shell as the riveting progresses. This equipment, together with the staging lumber, and one or two forges for heating the larger-sized rivets is all that is necessary. When several large tanks are to be erected, however, an air compressor is usually temporarily installed, and the heavier work is done with pneumatic tools, otherwise hand riveting and caulking is used. To secure the best results from a labor standpoint, the erection of three or four tanks should proceed simultaneously so that " bull " gang, riveters, and caulkers may each work only at their respective tasks.

Much miscellaneous construction can be carried out by independent gangs or contractors in the meantime, one of the first odd tasks necessary being the installation of an adequate water-supply system. Temporary shallow wells for the contractors' use are often necessary where city water is not available; but as the construction proceeds up to the period of operation more and more water is required daily, so that the work on permanent wells or other supply systems should be pushed rapidly. If condensing water is to be drawn from lake, river, or ocean source, the problem is then one of pump installation and the laying of water mains. In the meantime a temporary source of power may be had by by-passing large pumps with a small unit for immediate needs.

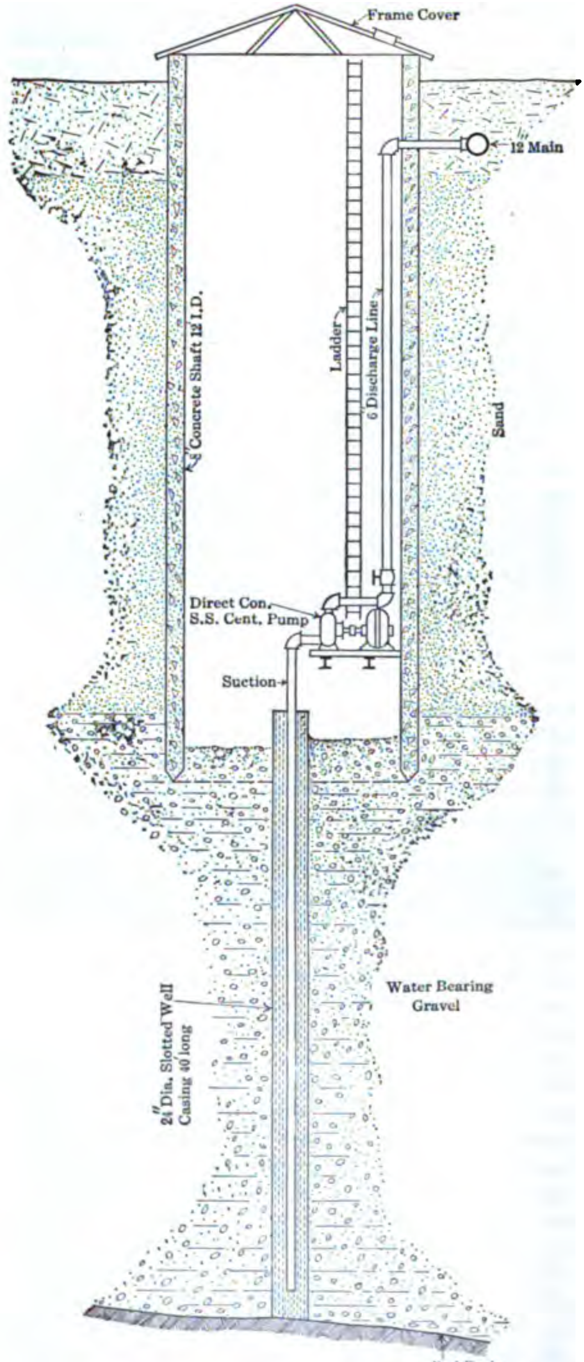


Fig. 136.—Sectional elevation concrete well shaft and casing screen.

Fire lines may be laid at this time, and service water drawn from hydrants at the point of demand, avoiding the stringing of temporary supply pipes.

Where the primal water supply is to be obtained from wells, the latter should be located by the methods already discussed, and if of the deep artesian type, drilling should be begun at once. When water exists in heavy flow at depths of from 25 to 50 feet, a brick or concrete shaft may be sunk from grade to water-bearing gravel by excavating from under the foundation shoes and allowing the curb to sink by gravity, as additional weight is supplied at the top. With the curb lowered to gravel, the casing should now be sunk. This may take the form of a perforated pipe, a slotted screen, or other patented form, and is dependent upon the nature of the strata which supply the water. The casing may be driven or sunk by weighting at the top and agitating the inner core with air or water under pressure. A completely sunk well shaft with casing screen in position is illustrated in Fig. 136. A submerged vertical centrifugal pump, with a motor at the top of the shaft, or a direct-connected standard unit located in the pit on a shelf above high-water mark, are the preferable types of pumps to be employed in installations of the above order. Sometimes, however, steam pumps at the bottom of the shaft and power pumps with the power head at the top of the curb are employed.

Where water lies at a depth of 50 to 300 feet, or even at depths permitting the cheaper sunk shaft and standard pump, the high-efficiency submerged vertical-well pump, in single or multi-stage type, as occasion demands, and driven by a vertical motor at grade, is perhaps the most satisfactory form of installation for securing a continuous water supply with minimum attention. One type of this pump has already been shown in Fig. 101, page 210; another type of high efficiency is illustrated, together with well shaft and casing, in Fig. 137.

Bunkering wharf.—Another item of refinery construction, that can and should be started early when it is to be installed at all, is a bunkering wharf. Such a structure is limited to plants on deep navigable water courses, and early erection is advisable, because at certain periods of the year, work is continually interrupted and frequently prevented by high water, ice and other disturbing causes. The construction of such a wharf is an individual problem for each site. It depends on depth of water, nature of channel, currents, number and size of steamers to be docked at one time, etc. A typical Mississippi River wharf is usually connected by an approach bridge passing over

FIG. 137.—A National multi-stage pump with screen encasing.

a levee to the plant site. One-half of the bridge is commonly reserved for filling and discharge lines, the other for trucking supplies, and as a foot passage.

The stringing and fitting up of connecting and run-down lines, as well as gas, water, and main steam lines is another division in erection that can be carried out without the interference of other projects. In general, gas and water lines [1] should be buried, the latter below frost level while oil lines may be trenched, partially exposed, or laid on top of the ground, depending upon climatic conditions. The ideal from of installation for such lines is one or more concrete trenches provided with cross beams for supporting lines above the bottom of the trench. The latter is frequently trapped to a sewer connection, so as to catch leakage and avoid accumulation of any quantity of oil with its attendant danger of fire. Steam lines should be supported initially at heights to permit drainage in decreasing sizes. Second-hand boiler flues often make ideal supports. Pipes should be hung from these boiler flues rather than supported directly, in order to secure greater freedom in expansion. In fitting, welding may be practiced where joints are likely to be permanent, as in a steam header manifold over a battery of boilers, or where special tightness is desired, as in gas-line connections to absorption or compression systems. Cast-iron (low-pressure service) pipe joints are either standard-flanged, lead-caulked, or of ground surface (Universal) type. While it is often possible by careful planning, to lay lines in such order that one ell at a turn is sufficient, such fitting, aside from making a stiff joint (poor practice in refinery construction), permits future additions with difficulty. The use of two ells, or an ell and tee at a branch connection, besides furnishing a partial swing, always allows future parallel lines to be installed, the latter slipping readily under branch lines without interference. Under severe conditions of expansion and contraction, such as a vapor line for instance, a full double-swing connection should be employed; while on hot-flow or pumping-out lines of smaller diameter either an expansion joint or double-swing may be used.

With the various lines nearing completion, drains and sewers should also be well along in construction so as to be in readiness for plant operation. These may be of split tile or concrete for open drains; standard tile pipe (earthenware, stoneware, concrete and in some cases cast iron) for medium-sized closed sewers; and of brick or reinforced concrete built over forms for large mains. In general, small drains should be of open type; but no great length of open sewer should exist without an interposed water-sealed trap to prevent spreading of fire. Closed earthenware tile should never be used where free steam discharges, nor should unprotected concrete be used where exposed to acid. All drains or sewers likely to carry oil should discharge into open traps or separators provided with skimming lines, before final wastage. Such traps, while still occasionally built of wood, in accordance with former practice, are now usually constructed of concrete. The size and number of compartments will vary with the amount of water handled. The main trap for a 6000-barrel plant running to lubricating oils, for instance, is 200 feet long by 30 feet wide by 10 feet deep, and is divided into six compartments. In one form of construction, cross walls parallel to the short side are built across the trap at regular intervals, forming pockets or compartments. The cross walls usually extend to within 2 feet of the bottom, allowing unimpeded flow of water below the partitions, the oil rising in the meantime to the surface, where it is removed from the several compartments by suitable skimming lines. A second form of construction also includes bottom baffles, which are located parallel to the cross walls about 3 feet from the same, and which force the water to take an upward course at regular intervals in its passage across the separator, thus aiding in the separation of the oil and in general efficiency of operation. Fig. 138 illustrates

[1] While wrought pipe is universally used for oil lines in refinery construction, cast-iron pipe is sometimes employed for low-pressure service water supply.

such a type of separator used for agitator waste. One-half is reserved for light-oil washings, the other for lubricating waste. This arrangement saves considerable rerunning of the recovered slops.

The employment of unlined concrete traps for agitator-waste recovery has not been a complete success, the cement being gradually eaten away by the acid wash water, and developing cracks and leaks; but where the traps are lined with acid-resisting brick, coated with separated acid flux, very fair service is given.

With the installation of equipment, completion of general construction, hooking

FIG. 138.—A concrete oil-separating trap.

up of lines, water-supply system, sewers, etc., the plant is now ready to operate; but foam lines to larger tanks, as well as hose attachment plugs, should be also finished—preferably before fires are lighted. Machinery guards, gear-wheel covers, railings, permanent walkways, and the many minor items which are important from a "safety first" standpoint should not be overlooked. Last but not of least importance is the matter of a substantial fence, difficult to climb and surrounding the entire refinery. In large plants, employing many construction gangs, and especially in congested districts, a fence is practically a necessity from the very beginning, in order to avoid liability suits, theft of materials and admittance of undesirables. The heavy all-steel fence with the top strung with barb wire is recommended.

General Construction Data, Material and Equipment

Foundations.—According to Kent,[1] the bearing power of soils of various nature is as follows:

Kind of material	Bearing Power in Tons per Square Foot	
	Minimum	Maximum
Rock—the hardest—in thick layers, in native bed....	200	
Rock equal to best ashlar masonry................	25	30
Rock equal to best brick masonry.................	15	20
Rock equal to poor brick masonry.................	5	10
Clay on thick beds, always dry.....................	4	6
Clay on thick beds, moderately dry................	2	4
Clay, soft...	1	2
Gravel and coarse sand, well cemented.............	8	10
Sand, compact, and well cemented..................	4	6
Sand, clean, dry...................................	2	4
Quicksand, alluvial, soils, etc......................	0.5	1

Where piling is required, as in soft clay and alluvial soils:

$$\text{Safe load in tons} = \frac{2Wh}{S+1}$$

where W = weight of hammer in tons;
h = height of fall of hammer in feet;
S = penetration under last blow, or the average under last five blows in inches.

Safe strength of brick piers, exceeding six diameters in height:

Piers laid with rich lime mortar, pounds per square inch, $110-5$ H/D.
Piers laid with 1 to 2 natural cement mortar, $140-5\frac{1}{2}$ H/D.
Piers laid with 1 to 3 Portland cement mortar, $200-6$ H/D.
H = height; D = least horizontal dimension, in feet.
Thickness of foundation walls:

Height of building	Office Buildings		Warehouses	
	Brick, inches	Stone, inches	Brick, inches	Stone, inches
Two stories........................	12 or 16	20	16	20
Three stories.......................	16	20	20	24
Four stories........................	20	24	24	28
Five stories........................	24	28	24	28
Six stories.........................	28	32	28	32

[1] Kent's Mechanical Engineers' Pocketbook, pp. 1585–1586.

Safe pressures on masonry in tons per square foot:

Granite, cut	40
Marble and limestone, cut	40
Sandstone, hard, cut	12
Hard-burned brick in Portland cement	15
Hard-burned brick in natural cement	9
Hard-burned brick in cement and lime	12
Hard-burned brick in lime mortar	8
Pressed brick in Portland cement	12
Pressed brick in natural cement	12
Rubble stone in natural cement	12

In foundations:

Dimension stone	30
Portland cement concrete	10
Natural cement concrete	4

Crushing strength of 12-inch cubes of concrete. (Kidder.)—Pounds per square foot. The concrete was made of 1 part Portland cement, 2 parts sand, with average concrete stone and gravel, as below:

	10 days	45 days	3 mos.	6 mos.	1 year
6 parts stone	130,750	172,325	324,875	361,600	440,040
3 parts stone, 3 gravel	136,750	266,962	....	298,037	396,200
4 parts stone, 2 gravel	....	....	....	....	408,300
6 parts ($\frac{3}{4}$ stone, $\frac{1}{4}$ granolithic)	....	....	....	....	388,700
6 parts average gravel	99,900	234,475	385,612	265,550	406,700
6 parts coarse stone, no fine	....	....	234,475	220,350	266,300

Reinforced concrete.—The building laws of New York, St. Louis, Cleveland and Buffalo, and the National Board of Fire Underwriters agreed in prescribing the following as the maximum allowable working stresses.

	Pounds, per square inch
Extreme fiber stress in compression in concrete	500
Shearing stress in concrete	50
Direct compression in concrete	350
Adhesion of steel to concrete	50
Tensile stress in steel	16,000
Shearing stress in steel	10,000

Lintels.—A lintel used over an opening in a solid brick wall is generally designed to support the weight of the wall directly over the girder for a height equal to one-third of the span. This is based on the fact that the probable line of rupture in the brick wall, if the lintel should be removed, would be inside the sides of an isosceles triangle whose base is the span and whose height is one-third of the span. The rule does not apply for green walls or walls having openings.

Beam			Steel Bearing Plates								Common Size Cast-iron Bearing Plates	
					Common brick with lime mortar. 100 pounds per square inch bearing pressure		Hard common select brick, mortar, 1 part Portland cement, 1 lime, 3 torpedo sand. 175 pounds per square inch bearing pressure		Portland cement concrete 1-2-4 mix. Machine mixed. 400 pounds per square inch bearing pressure			
Depth in inches	Weight, pounds per foot	Wall bearing in inches	Size in inches	Weight in pounds	Safe load in 1000 pounds on one plate	Limiting span in feet and inches	Safe load in 1000 pounds on one plate	Limiting span in feet and inches	Safe load in 1000 pounds on one plate	Limiting span in feet and inches	Size in inches	Weight including 2 per cent for over-weight, pounds
24	79.9	16	16×16×1	73	25.6	36′ 0″	44.8	20′ 9″	67.3	13′ 6″	16×16×2	136
20	65.4	16	16×16×1	73	25.6	24′ 6″	44.8	14′ 0″	60.5	10′ 3″	16×16×1¾	119
18	54.7	16	16×16×1	73	25.6	18′ 6″	44.8	10′ 6″	54.8	8′ 6″	16×16×1¾	119
15	42.9	12	12×16×¾	41	19.2	16′ 0″	20.9	15′ 0″	20.9	15′ 0″	12×16×1¼	64
12	31.8	12	12×12×¾	31	14.4	13′ 3″	25.2	7′ 6″	35.3	5′ 3″	12×12×1¼	48
10	25.4	8	8×12×⅝	17	9.6	13′ 6″	14.9	8′ 9″	14.9	8′ 9″	8×12×1	25
9	21.8	8	8×12×⅝	17	9.6	10′ 6″	13.6	7′ 6″	13.6	7′ 6″	8×12×1	25
8	18.4	8	8×8×⅝	12	6.4	11′ 9″	11.2	6′ 9″	25.6	3′ 0″	8×8×1	17
7	15.3	8	8×8×⅝	12	6.4	8′ 9″	11.2	4′ 9″	25.6	3′ 0″	8×8×1	17
6	12.5	6	6×6×½	5	3.6	10′ 9″	6.3	6′ 3″	14.4	2′ 0″	6×6×¾	7
5	10	6	6×6×½	5	3.6	7′ 0″	6.3	4′ 0″	14.4	2′ 0″	6×6×¾	7

Foundation Materials; Weights

Substance	Specific gravity	Weight per cubic foot, pounds
Excavated soil:		
Clay, dry	1.0	63
Clay, damp	1.8	110
Clay and gravel, dry	1.6	100
Earth, dry, loose	1.2	76
Earth, dry, packed	1.5	75
Earth, moist, loose	1.3	78
Earth, moist, packed	1.6	96
Earth, mud, flowing	1.7	108
Earth, mud, packed	1.8	115
Riprap, stone	1.3–1.4	80– 90
Riprap, shale	1.7	105
Sand, gravel, dry, loose	1.4–1.7	90–105
Sand, gravel, dry, packed	1.6–1.9	100–120
Sand, gravel, wet	1.9	118–120
Stone:		
Basalt	2.7–3.2	184
Dolomite	2.9	181
Gneiss, serpentine	2.4–2.7	159
Granite	2.5–3.1	175
Trap rock	2.8–3.2	187
Limestone	2.5–2.9	166
Marble	2.5–2.8	165
Sandstone	2.2–2.5	147
Shale, slate	2.6–2.9	172
Building Materials:		
Ashes, cinders	0.6–0.7	40–45
Slag, machine	1.5	96
Brick, common red	1.6	100
Brick, fire, silica	2.0	128
Cement, Portland, sacks	1.5	94
Lime, quick, loose lumps	0.8	53
Fire clay	2.0	150
Masonry:		
Concrete, neat cement	2.7–3.2	183
Concrete, stone, sand	2.2–2.4	144
Concrete, slag, etc	1.9–2.3	130
Concrete, cinder	1.5–1.7	100
Brick, common	1.8–2.0	120
Brick, pressed	2.2–2.3	140
Mortar, neat	1.4–1.9	103
Mortar, rubble, granite, etc	2.2–2.8	155
Mortar, rubble, limestone, etc	2.2–2.6	150
Mortar rubble, sandstone, etc	2.0–2.2	130
Ashlar, granite, etc	2.3–3.0	165
Ashlar, limestone, etc	2.3–2.8	160
Ashlar, sandstone, etc	2.1–2.4	140
Timber and piling (U. S. seasoned), moisture, 15 to 20 per cent:		
Cypress	0.48	30
Oak, live	0.95	59
Oak, red, black	0.65	41
Oak, white	0.74	46
Pine, yellow, longleaf	0.70	44
Locust	0.73	46

Brickwork.—A moderately hard-burned brick should be selected for refinery construction. A very hard brick cuts with difficulty, and a soft brick does not stand up under service conditions. Bricks containing quicklime (appearing as small white spots) should be rejected, since such brick will crack or disintegrate under the action of water. With dimensions varying from 7¾ inches to 8¼ inches in length, 4 inches to 4½ inches in width, and 2 inches to 2¼ inches in thickness, exact formulae for general computation are only possible where the size of the brick is definitely known, but the following scale is a fair estimating average:

	Pounds
7 bricks to a superficial foot 4-inch wall =	40
14 bricks to a superficial foot 9-inch wall =	90
21 bricks to a superficial foot 13-inch wall =	130
28 bricks to a superficial foot 18-inch wall =	180
35 bricks to a superficial foot 22-inch wall =	220

In still foundations, or other heavy walls of irregular shape, brick content can be best estimated on the basis of 19 bricks to the cubic foot, 18 bricks per cubic foot being another computing value for closely stacked new brick in piles; while loosely piled, cleaned, old bricks run about 17. Corners (except pillars) are measured only once, openings under 2 feet square not deducted, and arches counted from the spring.

For laying 1000 bricks in wall construction, 1¼ barrels of lime, ⅞ cubic yard of sand, and 1 sack of cement should be allowed; these quantities to be slightly increased in still walls, where full flushed joints should be specified. As to labor required, one bricklayer with tender will lay, as an average, from 1500 brick per day on 13-inch wall construction, up to 2000 and more on heavy walls, the number of tenders increasing with the rise in height and the number of brick handled.

Stonework.—Stonework is rarely used in refinery construction to-day, although occasionally wax-plant press vaults are built from the same, and sometimes ornamental office buildings. Wall measurement is by the perch (24¾ cubic feet), openings over 3 feet are deducted, with 1½ feet added to running measure for each jamb built, and arches solid from the spring. Corners of walls are measured twice; pillars less than 3 feet are measured three sides as linear length, obtaining the cubic contents by multiplying by fourth side times the depth; all foundations by cubic feet. For laying 1000 feet of stone, 1¼ barrels of lime, 1 cubic yard of sand, and 1 sack of cement are required; 150 feet of stone being an average day's work for one man and helper.

Concrete.—On account of occasional long storage, exposure to dampness, etc., cement should be carefully tested as received, during all periods of construction, not only by standard laboratory methods, but by frequent inspection of small batches taken from the mixers themselves under service conditions. The cement obtainable to-day is so generally uniform that failures in concrete construction, rather than being caused by an inferiority in cement, are more likely to be the result of one or more of the following causes:

1. Use of concrete of improper consistency; too little or too much water.
2. Insufficient cement in mixtures for stresses developed.
3. Insufficient mixing of concrete.
4. The use of unsuitable aggregates; either not properly graded, or containing clay, loam, etc.
5. The use of dirty water, or of water containing injurious chemicals.
6. Failure to keep concrete from drying out after placing, preventing it from hardening under the proper protection.
7. Premature removal, or use of dirty, or improperly braced forms.

8. Non-prevention of freezing before setting.
9. Engineering computations not in accordance with established principles of mechanics and accepted good practice.
10. Failure of reinforcement material to conform to standard specifications.
11. Failure to obtain good bond between fills.

Concrete is now widely used in refinery construction, particularly in locations adjacent to heated surfaces, such as still walls, or exposed to cold, as in press vaults, or subject to severe wear, and attrition, with floors likely to be oil soaked, etc. It is therefore obvious that the greatest care should be exercised in construction, and particularly in reinforced design. Computations should be checked with the minutest detail, and the design should show clearly the size and position of reinforcement.

While there are available for construction purposes, Portland, natural, and Puzzolan or slag cements, only the first-named should be used where subject to shock, vibrations, or stresses other than direct compression. Natural cement may be used in heavy foundations, where weight rather than strength is the essential feature, but neither this grade nor slag cement is recommended for general refinery service. Portland cement should meet the specifications of the American Society for Testing Materials.[1]

In addition to cement itself, aggregates should also be carefully inspected according to the specifications given on a previous page.

A table of recommended mixtures and maximum aggregate sizes for refinery construction follows:

	Recommended maximum size of aggregate in inches
1:1 :1 Mixture for:	
The wearing course of two-course floors subject to heavy trucking and handling of barrels, such as occurs in cooperage building, grease plant, shipping building, and loading platform	½
1:2 :3 Mixture for:	
Reinforced concrete roof slabs	1
One-course concrete road	3
One-course walks	1½
One-course concrete floors	1½
Sills and lintels without mortar surface	¾
Concrete draws	1
Reinforced concrete columns	1
Construction subjected to water pressure, such as traps, separators, cooling ponds, storage tanks, etc.	1
1:2 :4 Mixture for:	
Reinforced concrete walls, floors, beams, columns, and other concrete members designed in combination with steel reinforcing	1
Foundations for engines, pumps, rams, motors, etc., causing heavy loading impact and vibration	3
Concrete work in general subject to vibration	1½
Reinforced concrete sewer pipe	½

[1] See p. 129.

	Recommended maximum size of aggregate in inches
1 : 2½ : 4 Mixture for:	
Fuller's earth bins, and similar structures	1½
Building walls above foundation, when stucco finish will not be applied	1½
Walls of pits or basements, exposed to moisture	1½
Base of two-course road	3
1 : 2½ : 5 Mixture for:	
Walls above ground which are to have stucco finish	1½
Condenser supports, and wing walls, culverts, dams, small retaining walls	2
Basement walls and foundations where water-tightness is not essential	2
Foundations for small engines, pumps, motors, etc	2
1 : 3 : 6 Mixture for	
Mass concrete; large retaining walls, such as still foundations, footings, etc.	3
1 : 1½ Mixture for:	
Inside finish of tanks, and bin walls, where required, and for facing walls below ground when necessary to afford additional protection against the entrance of moisture. (To pass through No. 8 screen.)	
Back plastering of gravity retaining walls. (To pass through No. 8 screen.)	
1 : 2 Mixture for:	
Facing blocks and similar concrete products	½
Wearing course of two-course walks, floors, subjected only to light loads	¼
1 : 2½ Mixture for:	
Scratch coat of exterior plaster (cement and stucco). (To pass through No. 8 screen.)	
1 : 3 Mixture for:	
Intermediate and finish stucco coats. (To pass through No. 8 screen.)	
Concrete block when coarse aggregate is not used	¼
Concrete brick	¼
Concrete drain-tile and pipe when coarse aggregate is not used	¼

In computing the materials required for the mixtures recommended above, the following table will be of value:

Quantities of Materials Required for Various Mixtures of Mortar and Concrete *

Mixing materials for one bag batch				Resulting volume in cubic feet		Quantities of materials required for one cubic yard of compacted mortar or concrete			Quantities of materials required for one cubic foot of compacted mortar or concrete		
Ratio of mix	Cement in sacks	Sand, cubic feet	Pebbles or stone, cubic feet	Mortar	Concrete	Cement in sacks	Sand, cubic feet	Pebbles or stone, cubic feet	Cement in sacks	Sand, cubic feet	Pebbles or stone, cubic feet
1:1 :1	1	1	1	.....	2.2	12.5	12.5	12.5	0.46	0.46	0.46
1:2 :3	1	2.0	3.0	...	3.9	7.0	14.0	21.0	.26	.52	.78
1:2 :4	1	2.0	4.0	...	4.5	6.0	12.0	24.0	.22	.44	.89
1:2½:4	1	2.5	4.0	...	4.8	5.6	14.0	22.4	.21	.52	.83
1:2½:5	1	2.5	5.0	...	5.4	5.0	12.5	25.0	.19	.46	.92
1:3 :6	1	3.0	6.0	...	6.4	4.2	12.6	25.2	.16	.47	.94
1:1½	1	1.5	...	1.75	...	15.7	23.2	...	.57	.86	
1:2	1	2.0	...	2.1	...	12.8	25.6	...	.47	.95	
1:2½	1	2.5	...	2.5	...	11.0	27.5	...	.41	1.02	
1:3	1	3.0	...	3.8	...	9.6	28.8	...	.36	1.07	

* Adapted from "How to Work and Use Concrete," Portland Cement Association, May, 1920.

The proper protection of concrete after placing is a matter of essential importance, for although " setting " begins very shortly after all materials have been combined, chemical changes which result in thorough hardening take place rather slowly, and require adequate moisture to obtain final development. Freshly placed concrete, especially where exposed to sun and wind, or where forms have been early removed, is liable to dry out without attaining its full strength, unless it be kept thoroughly moist during the hardening process. Therefore all cement work, particularly floors, beams and other reinforced sections where excess water is likely to be absorbed or evaporated, should be daily sprinkled and protected by sand, where possible, for a period varying from ten days to two weeks, depending on climatic conditions. In winter weather, prevention of freezing before initial set takes place should be effected either by the use of heated materials, or by the covering of exposed surfaces with paper or boards over which sand, or preferably fresh manure, has been placed.

While no fixed rule can be given as to the time which should elapse before the removal of forms for all classes of concrete work, the following table will serve as a rough guide. It should in no sense be considered final. Temperature, climatic conditions, abnormally slow-setting batches, and differences in design affect the removal interval.

Average Expiration Period in Days for Form Removals

Class of construction	Warm weather	Cold weather
Heavy mass work walls* (still foundations, condenser supports, etc.)	1– 3	5– 8
Thin walls (drains, building walls, etc.)	2– 5	6– 9
Floor slabs (up to 6 feet span)	7–10	14–17
Beams and girders (long span)	12–15	21–28
Columns (assuming shored girders)	4– 7	9–12

* Removal of forms from mass concrete work, such as still foundations, condenser supports, etc., may be accomplished when the concrete suffers no indention from pressure of the thumb

In general, refinery concrete construction, at least for small plants where reinforced design does not enter into the problem, can be successfully carried out without the aid of special engineering advice, by following the precautions mentioned and employing the ratios of materials specified in the immediately preceding paragraphs. Where the amount of work involved is sufficient to warrant the erection of a tower and spouting system for the distribution of concrete, and especially where reinforced design enters into construction, the work should be carried out only under the direction of an engineer or by an experienced contractor. The point is especially emphasized that the design of reinforced concrete [1] structures is a separate branch of engineering, the mathematical analysis of the stresses, bending moments, etc., involving detailed computations, being quite beyond the scope of this volume; and while the following formulae are in accordance with the best present practice and may be used unconditionally, it is suggested that the designing of reinforced concrete work in general be referred to an engineer specializing in the art.

Reinforced concrete—Girders and floor beams.—The principles which are employed in structural steel construction also govern the arrangement of girders and floor beams. Cross beams may be omitted on short spans, or used only at columns to secure lateral stiffness. Since beams are usually designed as T-beams, a part of the floor slab is thus utilized as a part of the beam, but the width of the slab thus considered to act as a part of the beam should not exceed five times the thickness of the slab.

Floor slabs.—Small rods, woven wire, or metal fabric may be used for slab reinforcement. Cross reinforcement of small rods or wires laid parallel to supporting beams about 2 feet apart, is advisable to prevent cracks, shrinkage, etc. The entire load should be carried by transverse reinforcement if the length of the slab exceeds 1½ times its width. The load distribution on a rectangular slab supported by four sides and reinforced in both directions may be approximately determined by the formula

$$r=\frac{l^4}{l^4+b^4}$$

where r = the ratio of the load;
l = the length;
b = the width of the slab.

At the junction of the beam and the slab an effective bond should be provided, and where the principal slab reinforcement is parallel to the beam, transverse reinforcement should also be employed, extending over the beam and well into the slab.

Spacing of reinforcing bars.—Parallel bars should be spaced laterally not less than 2½ diameters, nor should the clear vertical space between layers of bars be less than ½ inch. From the edge or side of the beam or slab, the distance should not be less than 2 diameters.

Shear or web reinforcement.—Concrete may be assumed to carry one-fourth to one-third of the total shear in the calculation of web reinforcement; the remainder is taken by additional reinforcement arranged in intervals equal to the beam depth. Failure of beams by diagonal tension or shear is commonly prevented by the use of bent rods or stirrups in either inclined or vertical position. The longitudinal spacing of such rods or stirrups should not exceed three-fourths of the depth of the beam.

Formulae.[2]—The following formulae are based upon the following assumptions:

[1] For further information concerning reinforced concrete the reader is referred to Taylor and Thompson, Concrete, plain and reinforced; and to Turneaure and Maurer, Principles of reinforced concrete construction.

[2] From Final Report of the Joint Committee on Concrete and Reinforced Concrete, Amer. Soc. Civ. Eng., July 1, 1916.

1. The applied forces are perpendicular to the neutral plane.
2. The deformation of any fiber is proportional to its distance from the neutral axis.
3. The resisting moment of the beam is the sum of the moments above the neutral axis, due to the concrete area in compression, and of those below the neutral axis, due to the steel area in tension.
4. The tensile strength of the concrete is negligible.
5. The adhesion between the concrete and the reinforcement is perfect. Under compressive stress the two materials are therefore stressed in proportion to their moduli of elasticity.

I. Standard Notation

(a) *Rectangular beams.*

The following notation is recommended:

f_s = tensile unit stress in steel;
f_c = compressive unit stress in concrete;
E_s = modulus of elasticity of steel;
E_c = modulus of elasticity of concrete;
$n = \frac{E_s}{E_c}$;
M = moment of resistance, or bending moment in general;
A_s = steel area;
b = breadth of beam;
d = depth of beam to center of steel;
k = ratio of depth of neutral axis to depth d;
z = depth below top to resultant of the compressive stresses;
j = ratio of lever arm of resisting couple to depth d;
$jd = d - z$ = arm of resisting couple;
p = steel ratio $= \frac{A_s}{bd}$.

(b) *T-Beams.*

b = width of flange;
b' = width of stem;
t = thickness of flange;

(c) *Beams reinforced for compression.*

A' = area of compressive steel;
p' = steel ratio for compressive steel;
f_s' = compressive unit stress in steel;
C = total compressive stress in concrete;
C' = total compressive stress in steel;
d' = depth to center of compressive steel;
z = depth to resultant of C and C'.

(d) *Shear, bond and web reinforcement.*

V = total shear;
V' = total shear producing stress in reinforcement;
v = shearing unit stress;
u = bond stress per unit area of bar;

o = circumference or perimeter of bar;
Σ_0 = sum of the perimeters of all bars;
T = total stress in single reinforcing member;
s = horizontal spacing of reinforcing members.

(*e*) *Columns.*

A = total net area;
A_s = area of longitudinal steel;
A_c = area of concrete;
P = total safe load.

II. Formulæ

(*a*) *Rectangular beams.*

Position of neutral axis,

$$k = \sqrt{2pn + (pn)^2} - pn. \qquad (1)$$

Arm of resisting couple,

$$j = 1 - \tfrac{1}{3}k. \qquad (2)$$

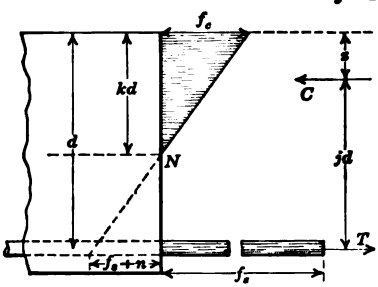


Fig. 139.—Diagram showing fiber stresses.

[For f_s = 15,000 to 16,000 and f_c = 600 to 650, j may be taken at $\tfrac{7}{8}$.]

Fiber stresses,

$$f_s = \frac{M}{A_s jd} = \frac{M}{pjbd^2}. \qquad (3)$$

$$f_c = \frac{2M}{jkbd^2} = \frac{2pf_s}{k}. \qquad (4)$$

Steel ratio, for balanced reinforcement,

$$p = \tfrac{1}{2} \cdot \frac{1}{\dfrac{f_s}{f_c}\left(\dfrac{f_s}{nf_c} + 1\right)}. \qquad (5)$$

(*b*) *T-Beams.*

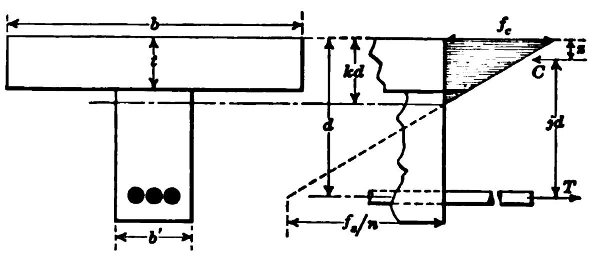


Fig. 140.—Diagram showing T-beams.

Case I. When the neutral axis lies in the flange. Use the formulae for rectangular beams.

Case II. When the neutral axis lies in the stem. The following formulae neglect the compression in the stem.

Position of neutral axis,

$$kd = \frac{2ndA_s + bt^2}{2nA_s + 2bt}. \qquad (6)$$

Position of resultant compression,

$$z=\frac{3kd-2t}{2kd-t}\cdot\frac{t}{3}. \quad \dots \quad (7)$$

Arm of resisting couple,

$$jd=d-z. \quad \dots \quad (8)$$

Fiber stresses,

$$f_s=\frac{M}{A_s jd}. \quad \dots \quad (9)$$

$$f_c=\frac{Mkd}{bt(kd-\frac{1}{2}t)jd}=\frac{f_s}{n}\cdot\frac{k}{1-k}. \quad \dots \quad (10)$$

(For approximate results the formulae for rectangular beams may be used.)

The following formulae take into account the compression in the stem: they are recommended where the flange is small compared with the stem:

Position of neutral axis,

$$kd=\sqrt{\frac{2ndA_s+(b-b')t^2}{b'}+\left(\frac{nA_s+(b-b')t}{b'}\right)^2}-\frac{nA_s+(b-b')t}{b'} \quad \dots \quad (11)$$

Position of resultant compression,

$$z=\frac{(kdt^2-\frac{2}{3}t^3)b+[(kd-t)^2(t+\frac{1}{3}(kd-t))]b'}{t(2kd-t)b+(kd-t)^2b'}. \quad \dots \quad (12)$$

Arm of resisting couple,

$$jd=d-z. \quad \dots \quad (13)$$

Fiber stresses,

$$f_s=\frac{M}{A_s jd} \quad \dots \quad (14)$$

$$f_c=\frac{2Mkd}{[(2kd-t)bt+(kd-t)^2b']jd} \quad \dots \quad (15)$$

(c) *Beams reinforced for compression.*

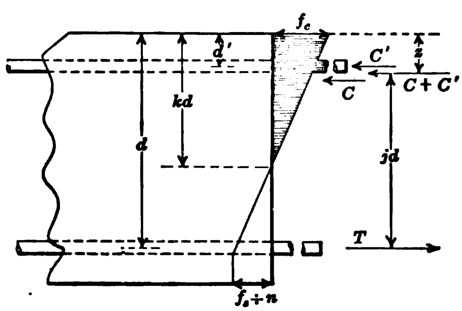


Fig. 141.—Diagram showing beams reinforced for compression.

Position of neutral axis,

$$k=\sqrt{2n\left(p+p'\frac{d'}{d}\right)+n^2(p+p')^2}-n(p+p'). \quad \dots \quad (16)$$

Position of resultant compression,

$$z=\frac{\frac{1}{3}k^3d+2p'nd'\left(k-\frac{d'}{d}\right)}{k^2+2p'n\left(k-\frac{d'}{d}\right)}. \qquad (17)$$

Arm of resisting couple,

$$jd=d-z. \qquad (18)$$

Fiber stresses,

$$f_c=\frac{6M}{bd^2\left[3k-k^2+\frac{6p'n}{k}\left(k-\frac{d'}{d}\right)\left(1-\frac{d'}{d}\right)\right]}. \qquad (19)$$

$$f_s=\frac{M}{pjbd^2}=nf_c\frac{1-k}{k} \qquad (20)$$

$$f_s'=nf_c\frac{k-\frac{d'}{d}}{k} \qquad (21)$$

(*d*) *Shear, bond, and web reinforcement.*

For rectangular beams,

$$v=\frac{V}{bjd}. \qquad (22)$$

$$u=\frac{V}{jd\cdot\Sigma_0} \qquad (23)$$

[For approximate results j may be taken at $\frac{7}{8}$.]

The stresses in web reinforcement may be estimated by means of the following formulae:

Vertical web reinforcement,

$$T=\frac{V's}{jd} \qquad (24)$$

Bars bent up at angles between 20 and 45° with the horizontal and web members inclined at 45°,

$$T=\frac{3}{4}\frac{V's}{jd}. \qquad (25)$$

For T-Beams,

$$v=\frac{V}{b'jd}. \qquad (26)$$

$$u=\frac{V}{jd\cdot\Sigma o}. \qquad (27)$$

[For approximate results j may be taken at $\frac{7}{8}$.]

(*e*) *Columns.*

Total safe load,

$$P = f_c(A_c + nA_s) = f_cA(1 + (n-1)p). \qquad (28)$$

Unit stresses,

$$f_c = \frac{P}{A(1+(n-1)p)}. \qquad (29)$$

$$f_s = nf_c. \qquad (30)$$

Bending moments.—Where slabs and girders are reinforced over supports to take care of negative bending moments, they act as continuous beams, and the bending moment at the center of the span is reduced. In computing the values of M, the following rules are considered good practice:

For floor slabs, M at center and at supports $= \frac{wl^2}{12}$

For beams, M at center and at supports $= \frac{wl^2}{12}$ (interior spans).

For beams, M at center and at supports $= \frac{wl^2}{10}$ (end spans).

Columns.—Column reinforcement may be effected by the use of longitudinal bars by bands or hoops, or by both; the general effect of the banding or hooping being to permit the use of somewhat higher working stresses.

Working stresses.—The following working stresses are in general use for reinforcing bars of medium structural steel, and good Portland cement and gravel concrete of a 1:2:4 or 1:2½:5 mixture:

	Pounds per square inch
f_c = unit compressive stress of concrete	650
f_v = unit shearing stress of concrete:	
straight reinforcement	30 to 40
special shear reinforcement	60 to 100
f_u = unit bond stress of concrete:	
smooth rods	60 to 80
deformed bars	100 to 175
f_s = unit tensile stress of steel	16,000
f_k = unit compressive stress of steel	10,000
$n = E_s \div E_c = 15$.	

Explanation of table: reinforced concrete slabs.—The following table is based upon the preceding formulæ for rectangular beams, upon fiber stresses of 650 pounds per square inch for concrete, and 16,000 pounds for steel bar or rod reinforcement.

The bending moments are given in foot-pounds per foot of width; below and to the left of the zigzag lines the values are determined by the maximum allowable fiber stress on steel; above and to the right they are determined by the maximum allowable stresses in concrete.

The first column gives the total thickness of the slab, the second, the distance from

Reinforced Concrete Slabs [1]

Bending moments in foot-pounds per foot of width

Allowable fiber stress; steel, 16,000 and concrete 650 pounds per square inch. $E_s \div E_c = 15$

Slab of 1 Square Foot			Area of Reinforcement in Square Inches per Foot of Width												
Thickness, inches	Distance a, inches	Weight, pounds	.10	.20	.30	.40	.50	.60	.70	.80	.90	1.00	1.10	1.25	1.50
2½	¾	30	209	353											
3	¾	36	272	525	599										
3½	¾	42	335	650	858										
4	¾	48	398	775	1135	1254									
4½	¾	54	461	900	1235	1584									
5	1	60	497	961	1412	1766	1894								
5½	1	66	558	1087	1600	2101	2312								
6	1	72	621	1213	1787	2349	2760	2922							
6½	1	78	686	1340	1975	2596	3205	3431							
7	1	84	751	1466	2162	3844	3515	3974	4173						
7½	1¼	90	783	1531	2257	2969	3669	4254	4465						
8	1¼	96	....	1658	2446	3218	3977	4728	5097	5309	5494	5674			
8½	1¼	102	....	1785	2634	3467	4288	5099	5734	5982	6206	6410			
9	1½	108	....	1849	2730	3594	4444	5283	6069	6338	6574	6790			
9½	1½	114	....	1977	2919	3845	4757	5656	6543	7063	7330	7575			
10	1½	120	....	2104	3109	4096	5068	6027	6974	7826	8120	8392			
10½	1¾	126	....	....	3205	4222	5224	6213	7192	8163	8525	8817	9079	9432	9039
11	1¾	132	....	....	3395	4475	5537	6588	7625	8652	9359	9681	9972	10369	10936
11½	1¾	138	....	....	3586	4726	5850	6960	8058	9145	10224	10575	10898	11337	11969
12	2	144	....	....	3681	4852	6007	7148	8276	9393	10500	11037	11376	11858	12494

[1] Concrete mixture 1 : 2 : 4 or 1 : 2½ : 5 carefully graded.

the center of the steel to the bottom of the slab, and the third the approximate weight of concrete slabs 1 foot square.

Example.—Required the reinforcement for a slab continuous at four sides and 5 inches thick, to carry a superimposed load of 150 pounds per square foot over a clear span of 8 feet.

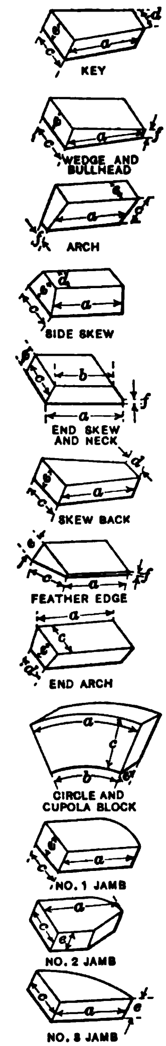


FIG. 142.—Shapes and sizes of fire-brick.

Assuming the weight of the concrete slab in pounds at twelve times the thickness of the slab in inches, then the weight of the slab per foot is $12\times5=60$ pounds, and the total weight, W, for a span of 8 feet is $(60+150)\times8=1680$ pounds.

$$M=\frac{WL}{12}=\frac{1680\times8}{12}=1120 \text{ foot-pounds.}$$

The required structural steel bar area, by reference to the table below is, by interpolation, 0.24 square inch; and the sizes may be chosen from rounds, squares or special shapes as may be elected.

Fire-brick.—Fire-brick for general refinery use should be of medium grade, and of good wearing quality rather than of a composition required to withstand abnormally high temperatures. In Dutch-oven construction, pressure still and stoker settings, arches, etc., only the best grade of No. 1 brick should be employed, all header courses being preferably laid in fire-boxes, or where otherwise exposed to severe duty. Failure in service is as likely to be the result of fault in laying, as of the use of inferior brick; and too much emphasis cannot be laid on the necessity of hammering bricks in place, dipped with the thinnest bond of clay slip. For arches, kiln linings, etc., 250 pounds of fire-clay per 1000 brick is sufficient and for ordinary work 350 to 400 pounds. Tight, close-fitting courses are far superior to cracks and patent high temperature cements. Proper wedges, arch brick, and skews will not only save their cost many times in cutting labor; but, what is more to the point, will help to produce a tight-fitting job, essential to permanency. The laying of 500 well-fitted brick per day per bricklayer is ultimately far more advantageous than the laying of twice that number poorly placed. Since all manufacturers have adopted a standard schedule of sizes, reference to the appended table will be a sufficient guide for all ordinary construction; special rotary-kiln shapes are usually obtainable on comparatively short notice from the manufacturers.

Chemical analyses, within the usual meaning of the term, are without great significance as an index to refractoriness or wearing quality, as shown by the following table. Several well-known makes, for instance, closely agree in heat-resisting qualities, but have a variation of 10 to 15 per cent in silica content. Analysis has a certain value, as a check on deliveries, but it appears that the fineness and physical nature of the materials entering into the composition of a brick have much to do with its refractory index, and it is suggested that the microscope may be of aid in establishing quality.

Shapes and Sizes of Fire-brick

Name of brick or tile	Length, Inches		Width, Inches		Thickness, Inches		No. of brick to circle	Inside diam. of circle, inches
	Long edge, *a*	Short edge, *b*	Long edge, *c*	Short edge, *d*	Maximum, *e*	Minimum, *f*		
Straight brick:								
9-inch	9	......	$4\frac{1}{2}$	......	$2\frac{1}{2}$			
Large 9-inch	9	......	$6\frac{3}{4}$	......	$2\frac{1}{2}$			
Small 9-inch	9	......	$3\frac{1}{2}$	......	$2\frac{1}{2}$			
Checker	9	......	3	......	3			
Soap	9	......	$2\frac{1}{2}$	......	$2\frac{1}{4}$			
No. 1 split	9	......	$4\frac{1}{2}$	......	$1\frac{1}{4}$			
No. 2 split	9	......	$4\frac{1}{2}$	......	2			
Checker tile	18, 20, 24	......	6	......	3			
Mill tile	18, 20, 24	......	9	......	3			
Mill block	18	......	9	......	6			
No. 1 bridgewall	13	......	$6\frac{1}{2}$	......	6			
No. 2 bridgewall	13	......	$6\frac{1}{2}$	......	3			
Wedge shape and taper bricks:								
Large 9-inch No. 1 wedge	9	......	$6\frac{3}{4}$	......	$2\frac{1}{2}$	$1\frac{7}{8}$	102	60
Large 9-inch No. 2 wedge	9	......	$6\frac{3}{4}$	......	$2\frac{1}{2}$	$1\frac{1}{2}$	63	30
No. 1 wedge	9	......	$4\frac{1}{2}$	......	$2\frac{1}{2}$	2	102	60
No. 2 wedge	9	......	$4\frac{1}{2}$	......	$2\frac{1}{2}$	$1\frac{1}{2}$	63	30
No. 1 key*	9	......	$4\frac{1}{2}$	4	$2\frac{1}{2}$	......	112	144
No. 2 key*	9	......	$4\frac{1}{2}$	$3\frac{1}{2}$	$2\frac{1}{2}$	......	65	72
No. 3 key*	9	......	$4\frac{1}{2}$	3	$2\frac{1}{2}$	......	41	36
No. 4 key*	9	......	$4\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{1}{2}$	......	26	18
No. 1 arch†	9	......	$4\frac{1}{2}$	......	$2\frac{1}{2}$	2	72	48
No. 2 arch†	9	......	$4\frac{1}{2}$	......	$2\frac{1}{2}$	$1\frac{1}{2}$	42	24
Side skew	9	......	$4\frac{1}{2}$	$1\frac{3}{4}$	$2\frac{1}{2}$	0		
End skew	9	7	$4\frac{1}{2}$	......	$2\frac{1}{2}$	0		
Skew back	9	......	$4\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{2}$	......		
No. 1 neck	9	$4\frac{1}{2}$	$4\frac{1}{2}$	......	$2\frac{1}{2}$	......		
No. 2 neck	9	2	$4\frac{1}{2}$	......	$2\frac{1}{2}$	......		
No. 3 neck	9	0	$4\frac{1}{2}$	......	$2\frac{1}{2}$	$\frac{5}{8}$		
Feather edge	9	......	$4\frac{1}{2}$	......	$2\frac{1}{2}$	$\frac{1}{8}$		
Jamb	9	......	$4\frac{1}{2}$	......	$2\frac{1}{2}$	......		
Bullhead	9	......	$4\frac{1}{2}$	......	3	2	......	36
Edge arch	9	......	$4\frac{1}{2}$	3	$2\frac{1}{2}$	......		
Circle brick, curved edges:								
No. 1	$8\frac{1}{2}$	$5\frac{1}{4}$	$4\frac{1}{2}$	......	$2\frac{1}{2}$	......	9	15
No. 2	9	$6\frac{9}{16}$	$4\frac{1}{2}$	......	$2\frac{1}{2}$	......	11	24
No. 3	9	$7\frac{3}{16}$	$4\frac{1}{2}$	......	$2\frac{1}{2}$	......	14	36
No. 4	9	$7\frac{9}{16}$	$4\frac{1}{2}$	....	$2\frac{1}{2}$	......	20	48
No. 5	9	$7\frac{5}{8}$	$4\frac{1}{2}$	......	$2\frac{1}{2}$	......	24	60
Cupola blocks:								
No. 1	9	$6\frac{3}{8}$	6	......	4	......	15	30
No. 2	9	$6\frac{3}{4}$	6	......	4	......	17	36
No. 3	9	$7\frac{1}{8}$	6	......	4	......	21	48
No. 4	9	$7\frac{1}{2}$	6	......	4	......	52	60

* Tapers lengthwise. † Tapers breadthwise.

Refractoriness of some American Fire-brick *

Number of sample	Locality	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Alkaline earths and alkalies	Sum of fluxes	Cone of fusion
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	No.
1	Missouri......	51.59	38.26	1.84	1.97	6.34	10.25	32 to 33
2	Kentucky.....	54.90	38.19	2.18	1.55	3.18	6.91	32 to 33
3	Pennsylvania..	53.05	41.16	2.65	1.80	1.34	5.79	32 to 33
4	Colorado......	93.57	2.53	0.62	0.27	3.01	3.90	32 to 33
5	Kentucky.....	44.77	43.08	2.78	2.54	6.83	12.15	31 to 32
6	New York....	68.70	20.75	1.20	5.54	3.81	10.55	31 to 32
40	Pennsylvania..	61.28	27.13	2.90	1.37	7.31	11.58	26
41	Pennsylvania..	74.83	16.40	3.26	0.77	4.74	8.77	26
42	Alabama......	67.19	25.05	2.83	0.71	4.22	7.76	26
43	Indiana.......	60.76	31.66	5.67	1.58	0.33	7.58	26
44	Kentucky.....	60.58	32.49	2.25	1.69	2.99	6.93	26

* Kent's Mechanical Engineers' Pocketbook, p. 268.

[1] Fairly uniform, angular, flint-clay particles, constituting body of brick. Largest pieces 5 to 6 mm. in diameter. White.

[2] Coarse-grained; angular pieces of flint-clay as large as 9 mm. Average 4 to 5 mm. Light buff.

[3] Coarse, angular flint-clay particles, varying from 1 to 5 mm. in diameter. Average 4 to 5 mm. Buff.

[4] Fine-grained quartz particles. Largest 2 to 3 mm. in diameter. White.

[5] Medium grain; flint-clay particles, fairly uniform in size, 3 to 4 mm. Light buff.

[6] Coarse grain; quartz particles, 4 to 5 mm. in diameter, forming about 50 per cent of brick. White.

[40] Fine grain; small, white flint-clay particles, not over 2 mm. in diameter and not abundant. Buff.

[41] Medium grain; pieces of quartz with pinkish color and angular flint-clay particles. About 3 mm. in diameter. Buff.

[42] Fine grain; even texture. Few coarse particles. Brown.

[43] Fine grain; some particles as large as 1 to 2 mm. in diameter. Buff.

[44] Angular, dark-colored, flinty-clay particles. Maximum size 5 mm. Throughout a reddish-brown matrix.

Construction materials; miscellaneous—iron and steel.—Of the various items used in refinery construction, the basic products of the iron and steel industry take precedence of all others and may be described as follows:

Plates.—Plate, as used by the refining industry is graded as tank, pressing, flange, firebox, and still-bottom steel. It is sold at a certain weight base price with extras for gage, width, and number of cuttings required. Complete specifications for various grades of steel and tables of weight and gages may be found in the General Tables.[1]

Rivets.—Except on structural frame work, during initial erection of refinery buildings, where button-head structural rivets are used, there are only two classes of rivets widely employed in refinery practice; i.e., conehead boiler quality, and soft flat-head tank rivets. The former are usually driven to a flat steeple head, especially in sizes over ½ inch, where they are hot-driven with a pneumatic hammer, but are occasionally countersunk-driven (agitator-cone construction). Tank rivets are almost invariably driven flat by hand. The basis of rivet measurement up to ½ inch in diameter is the

[1] See p. 775, Vol. II.

Name	Source	Use
	Wrought	
Plate (flats)	Rolled from ingot slabs	Tanks, stills, general
Sheets (black, galv., tin)	Rolled from ingot bars	Roofs, drums, cans
Rods (rounds, squares)	Rolled from ingot billets	Reinforcing, general
Structural shapes	Rolled from ingot blooms	General structural purposes
Pipe (tubing)	Welded from skelp flats	Oil, gas, water lines, etc.
Tubing (seamless)	Punched and rolled from billets.	Pressure stills, etc.
Rivets (bolts)	Headed from rods	General
Chain	Welded from rods	General
Wire (screen, fence, nails)	Die drawn from rods	General
	Cast	
Iron castings	Cupola-melted foundry pig and scrap	Cast-iron pipe, fittings, general
Malleable castings	Cupola-melted from malleable pig and heated in scale	General severe service
	Produced	
Acid O. H. steel	Pig and scrap, open-hearth melted and purified in (silica) acid bath	General refinery use
Basic O. H. steel	Pig and scrap, open-hearth melted and purified in basic (dolomite) bath	Unsuitable general refinery use
Basic O. H. steel	Impurities reduced to one-tenth of one per cent	Used under various grade names for roofs, etc., as equivalent to genuine wrought iron*
Crucible steel	Crucible melted steel with charcoal, vanadium, titanium, etc.	Tool and high-speed steel
Genuine wrought iron	Gray foundry pig and iron ore puddled in reverberatory furnace	Genuine wrought-iron pipe, tubes, sheet, etc.

* In genuine wrought iron, i.e. puddled iron, analysis will run about as follows:

Carbon below	0.100	per cent phosphorus, as high as 0.200
Sulphur about	0.020–0.025	
Manganese about	0.025	
Silicon about	0.200	

If phosphorus is 0.200 per cent or over and maganese low with silicon high, metal is genuine wrought iron; since it is impossible to roll steel containing 0.200 per cent or over of phosphorus with practically no manganese. Naturally some wrought iron will run low in phosphorus, but puddled iron is never low in silicon, containing as it does 0.5–1.0 per cent of slag.

Birmingham wire gage; from 1/4 to 1 inch standard scant measurement; and above 1 inch exact diameter. Tables of weights of sizes most used are listed below, together with a length table for various grips. Table for Birmingham wire gage applicable to such rivets is found on page 775 of the General Tables.

Flat-head Tank Rivets

Approximate number in 100 pounds

Length under head. Size	Scant Size						
	1/8	3/16	1/4	5/16	3/8	7/16	1/2
3/8	20,400	18,800					
1/2	17,500	15,900	8000	5100	3200		
5/8	16,000	13,800	7000	4500	2900		
3/4	14,400	12,200	6300	4100	2600	1429	1083
7/8	13,500	10,900	5700	3700	2400	1335	1027
1	12,600	9,800	5200	3400	2200	1222	940
1 1/8	11,600	9,000	4700	3100	2000	1092	840
1 1/4	10,800	8,300	4400	2900	1900	1036	797
1 3/8	10,000	7,600	4100	2700	1800	988	760
1 1/2	9,300	7,100	3800	2500	1700	949	730

Dimensions of Rivets

Boiler rivets

$T=\frac{15}{16}\times D,\quad H=\frac{7}{8}\times D,\quad W=1\frac{3}{4}\times D,\quad H=D,\quad W=2\times D$

Cone Head				Steeple Head		
Diameter, D	Width, T	Height, H	Width, W	Diameter, D	Height, H	Width, W
1/2	15/32	7/16	7/8	1/2	1/2	1
9/16*	17/32	31/64	63/64	9/16*	9/16	1 1/8
5/8	19/32	35/64	1 3/32	5/8	5/8	1 1/4
11/16	41/64	39/64	1 13/64	11/16	11/16	1 3/8
3/4	45/64	21/32	1 5/16	3/4	3/4	1 1/2
13/16	49/64	23/32	1 27/64	13/16	13/16	1 5/8
7/8	13/16	49/64	1 17/32	7/8	7/8	1 3/4
15/16	7/8	13/16	1 41/64	15/16	15/16	1 7/8
1	15/16	7/8	1 3/4	1	1	2
1 1/16*	1	15/16	1 55/64	1 1/16*	1 1/16	2 1/8
1 1/8	1 1/16	63/64	1 31/32	1 1/8*	1 1/8	2 1/4
1 3/16*	1 7/64	1 1/32	2 5/64	1 3/16*	1 3/16	2 3/8
1 1/4*	1 11/64	1 3/32	2 3/16	1 1/4*	1 1/4	2 1/2
1 3/8*	1 9/32	1 13/64	2 13/32	1 3/8*	1 3/8	2 3/4
1 1/2*	1 13/32	1 5/16	2 5/8	1 1/2*	1 1/2	3

* Special sizes.

Weight of 100 Cone-head Rivets

Length under head, inches	Scant Diameter, Inches									
	½	9/16	⅝	11/16	¾	13/16	⅞	1	1⅛*	1¼*
¾	8.6	11.9	15.5							
⅞	9.3	12.7	16.5							
1	9.9	13.6	17.6	22.4	28.1	34.5				
1⅛	10.6	14.4	18.6	23.6	29.6	36.3				
1¼	11.2	15.2	19.6	24.9	31.1	38.1	46	65		
1⅜	11.9	16.1	20.7	26.1	32.6	39.8	48	68	93	
1½	12.5	16.9	21.7	27.4	34.1	41.6	50	70	96	127
1⅝	13.2	17.7	22.7	28.6	35.6	43.4	52	73	100	132
1¾	13.8	18.6	23.8	29.9	37.1	45.1	54	76	103	136
1⅞	14.5	19.4	24.8	31.1	38.6	46.9	56	78	107	140
2	15.1	20.2	25.8	32.4	40.1	48.7	58	81	110	145
2⅛	15.8	21.0	26.9	33.7	41.6	50.5	60	84	114	149
2¼	16.4	21.9	27.9	34.9	43.1	52.2	62	87	117	153
2⅜	17.1	22.7	28.9	36.2	44.6	54.0	64	89	121	158
2½	17.8	23.5	30.0	37.4	46.1	55.8	66	92	124	162
2⅝	18.4	24.4	31.0	38.7	47.6	57.5	68	95	128	166
2¾	19.1	25.2	32.0	39.9	49.1	59.3	70	97	132	171
2⅞	19.7	26.0	33.1	41.2	50.6	61.1	72	100	135	175
3	20.4	26.9	34.1	42.5	52.1	62.8	74	103	139	179
3¼	21.7	28.5	36.2	45.0	55.1	66.4	78	108	146	188
3½	22.9	30.2	38.2	47.5	58.1	69.9	83	114	153	197
3¾	24.3	31.9	40.3	50.0	61.1	73.4	87	119	160	205
4	25.6	33.5	42.4	52.5	64.1	77.0	91	124	167	214
4¼	26.9	35.2	44.4	55.0	67.1	80.5	95	130	174	223
4½	28.2	36.9	46.5	57.5	70.1	84.0	99	135	181	232
4¾	29.5	38.5	48.6	60.0	73.1	87.6	103	141	188	240
5	30.8	40.2	50.6	62.6	76.1	91.1	107	146	195	249
5¼	32.1	41.9	52.7	65.1	79.1	94.6	111	151	202	258
5½	33.4	43.5	54.8	67.6	82.1	98.2	115	157	209	266
5¾	34.7	45.2	56.8	70.1	85.1	101.7	120	162	216	275
6	36.0	46.8	58.9	72.6	88.1	105.2	124	167	223	284
6½	38.7	50.2	63.0	77.6	94.1	112.3	132	178	237	301
7	41.3	53.5	67.2	82.7	100.2	119.4	140	189	251	319
Weight of heads....	4.7	6.9	9.3	12.3	16.1	20.4	26	38	54	75

* All rivets larger than 1 inch are made to exact diameter.

Length of Rivets Required for Various Grips

Grip a	Diameter, Inches					Grip b	Diameter, Inches				
	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1		$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
$\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{3}{8}$
$\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{1}{4}$	$\frac{5}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$
$\frac{3}{4}$	$1\frac{3}{4}$	2	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$\frac{3}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{5}{8}$
$\frac{7}{8}$	$1\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{3}{4}$
1	2	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{5}{8}$	1	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{7}{8}$
$\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	$\frac{1}{4}$	$1\frac{7}{8}$	2	2	$2\frac{1}{8}$	$2\frac{1}{8}$
$\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{7}{8}$	3	$3\frac{1}{8}$	$3\frac{1}{4}$	$\frac{1}{2}$	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{3}{8}$	$2\frac{1}{2}$
$\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{7}{8}$
2	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{7}{8}$	2	$2\frac{3}{4}$	$2\frac{7}{8}$	3	3	$3\frac{1}{8}$

The efficiency of a riveted joint is the ratio of a unit of riveted length to the same unit of solid plate, the following signs and formulæ being in general accepted use:

Efficiency of riveted joints.—A.S.M.E. Boiler Code, 1918.

X = efficiency = ratio of strength of unit length of riveted joint to the strength of the same length of a solid plate.
T = tensile strength of the material, in pounds per square inch.
t = thickness of plate, in inches.
b = thickness of butt strap, in inches.
P = pitch of rivets, in inches, on the row having the greatest pitch.
d = diameter of rivet, after driving, in inches.
a = cross-section of rivet after driving, in square inches.
s = strength of rivet in single shear, in pounds per square inch.
S = strength of rivet in double shear, in pounds per square inch.
c = crushing strength of rivet, in pounds per square inch.
n = number of rivets in single shear in a length of joint equal to P.
N = number of rivets in double shear in the same length of joint.

For single-riveted lap joints:

A = strength of solid plate = PtT.
B = strength of plate between rivet holes = $(P-d)tT$.
C = shearing strength of one rivet = nsa.
D = crushing strength of plate in front of one rivet = dtc.

$$X=\frac{B}{A} \text{ or } \frac{C}{A} \text{ or } \frac{D}{A}, \text{ whichever is least.}$$

For double-riveted lap joints:

A and B as above, C and D to be taken for two rivets.
$X = B$, C, or D (whichever is least) divided by A.

For butt and double strap joint, double-riveted:

A = strength of solid plate = PtT.
B = strength of plate between rivet holes in the outer row = $(P-d)tT$.

C = shearing strength of two rivets in double shear, plus shearing strength of one rivet in single shear = $NSa + nsa$.

D = strength of plate between rivet holes in the second row, plus the shearing strength of one rivet in single shear in the outer row = $(P - 2d)tT + nsa$.

E = strength of plate between rivet holes in the second row, plus the crushing strength of butt strap in front of one rivet in the outer row = $(P - 2d)tT + dbc$.

F = crushing strength of plate in front of two rivets, plus the crushing strength of butt strap in front of one rivet = $Ndtc + ndbc$.

G = crushing strength of plate in front of two rivets, plus the shearing strength of one rivet in single shear = $Ndtc + nsa$.

$X = B$, C, D, E, F, or G (whichever is least) divided by A.

For butt and double strap joint, triple-riveted:

The same as for double-riveted, except that four rivets instead of two are taken for N in computing C, F, and G.

For butt and double strap joint, quadruple-riveted:

A, B, and D the same as for double-riveted joints.

C = shearing strength of eight rivets in double shear and three rivets in single shear = $NSa + nsa$.

E = strength of plate between rivet holes in the third row (the outer row being the first) plus the shearing strength in single shear of two rivets in the second row and one rivet in the outer row = $(P - 4d)tT + nsa$.

F = strength of plate between rivet holes in the second row, plus the crushing strength of butt strap in front of one rivet in the outer row = $(P - 2d)$ $tT + dbc$.

G = strength of plate between rivet holes in the third row, plus the crushing strength of butt strap in front of two rivets in the second row and one rivet in the outer row = $(P - 4d)tT + ndbc$.

H = crushing strength of plate in front of eight rivets, plus the crushing strength of butt strap in front of three rivets = $Ndtc + ndbc$.

I = crushing strength of plate in front of eight rivets, plus the shearing strength in single shear of two rivets in the second row and one in the outer row = $Ndtc + nsa$.

$X = B$, C, D, E, F, G, H, or I (whichever is least) divided by A.

The A.S.M. Boiler Code also allows 95,000 pounds per square inch for crushing strength, but for shearing strength of rivets allows:

In single shear, iron 38,000; steel 44,000.

In double shear, iron 76,000; steel 88,000.

As a typical example, the computation of the efficiency of the single-riveted lap joint illustrated below, is given in detail for ¼-inch plate riveted with ⅝-inch diameter rivets. Lack of space prevents further application of the above rules,[1] but the efficiencies of various types of joints, all in accordance with the best standard practice, are further included for empirical consideration.

[1] For additional examples of computations involving efficiency of joint, see A. S. M. E. Boiler Code, latest edition.

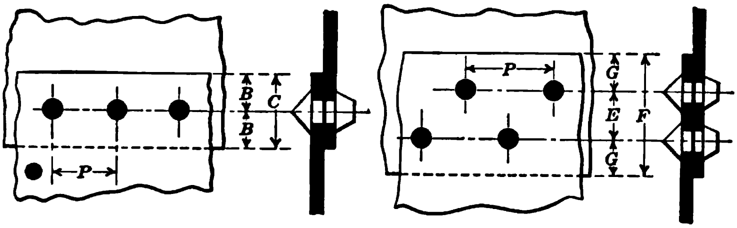


FIG. 143.—Single- and double-riveted lap joints.

Proportions of Single- and Double-riveted Lap Joints

All dimensions are in inches

Thickness of plate	Diameter of rivet	Diameter of hole	SINGLE-RIVETED LAP JOINT Dimensions			Per cent efficiency of joint	DOUBLE-RIVETED LAP JOINT Dimensions				Per cent efficiency of joint
			P	*B*	*C*		*P*	*E*	*F*	*G*	
$\frac{1}{4}$	$\frac{1}{2}$	$\frac{9}{16}$	$1\frac{1}{8}$	1	2	50	$1\frac{13}{16}$	$1\frac{3}{4}$	$3\frac{3}{4}$	1	69
$\frac{1}{4}$	$\frac{5}{8}$	$\frac{11}{16}$	$1\frac{5}{8}$	$1\frac{1}{8}$	$2\frac{1}{4}$	57	$2\frac{5}{8}$	$1\frac{7}{8}$	$4\frac{1}{8}$	$1\frac{1}{8}$	72
$\frac{5}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$1\frac{3}{8}$	$1\frac{1}{8}$	$2\frac{1}{4}$	50	$2\frac{3}{16}$	$1\frac{5}{8}$	$3\frac{7}{8}$	$1\frac{1}{8}$	68
$\frac{5}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$1\frac{7}{8}$	$1\frac{1}{4}$	$2\frac{1}{2}$	56	$2\frac{1}{2}$	$1\frac{3}{4}$	$4\frac{1}{4}$	$1\frac{1}{4}$	72
$\frac{3}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$1\frac{11}{16}$	$1\frac{1}{4}$	$2\frac{1}{2}$	52	$2\frac{9}{16}$	$1\frac{7}{8}$	$4\frac{3}{8}$	$1\frac{1}{4}$	68
$\frac{3}{8}$	$\frac{7}{8}$	$\frac{15}{16}$	$2\frac{1}{8}$	$1\frac{7}{16}$	$2\frac{7}{8}$	55	$3\frac{1}{4}$	$2\frac{1}{4}$	$5\frac{1}{8}$	$1\frac{7}{16}$	71
$\frac{7}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{4}$	$2\frac{1}{2}$	47	$2\frac{5}{16}$	$1\frac{7}{8}$	$4\frac{3}{8}$	$1\frac{1}{4}$	65
$\frac{7}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	$1\frac{15}{16}$	$1\frac{7}{16}$	$2\frac{7}{8}$	51	$2\frac{15}{16}$	$2\frac{1}{8}$	5	$1\frac{7}{16}$	67
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{15}{16}$	$1\frac{13}{16}$	$1\frac{7}{16}$	$2\frac{7}{8}$	48	$2\frac{11}{16}$	2	$4\frac{7}{8}$	$1\frac{7}{16}$	65
$\frac{1}{2}$	1	$1\frac{1}{16}$	$2\frac{3}{16}$	$1\frac{5}{8}$	$3\frac{1}{4}$	51	$3\frac{5}{16}$	$2\frac{1}{4}$	$5\frac{1}{2}$	$1\frac{5}{8}$	68
$\frac{9}{16}$	1	$1\frac{1}{16}$	$2\frac{1}{8}$	$1\frac{5}{8}$	$3\frac{1}{4}$	47	$3\frac{1}{16}$	$2\frac{1}{8}$	$5\frac{3}{8}$	$1\frac{5}{8}$	65
$\frac{5}{8}$	$1\frac{1}{8}$	$1\frac{3}{16}$	$2\frac{3}{8}$	$1\frac{3}{4}$	$3\frac{1}{2}$	48	$3\frac{3}{4}$	$2\frac{3}{8}$	$5\frac{7}{8}$	$1\frac{3}{4}$	68

$T = 55{,}000$ pounds per square inch.
$t = \frac{1}{4}$ inch $= 0.25$ inch.
$P = 1\frac{5}{8}$ inch $= 1.625$ inch.
$d = \frac{11}{16}$ inch $= 0.6875$ inch.
$a = 0.3712$ square inch.
$s = 44{,}000$ pounds per square inch.
$c = 95{,}000$ pounds per square inch.
$A = PtT = 1.625 \times 0.25 \times 55{,}000 = 22{,}343.$
$B = (1.625 - 0.6875)\ 0.25 \times 55{,}000 = 12{,}890.$
$C = 1 \times 44{,}000 \times 0.3712 = 16{,}332.$
$D = 0.6875 \times 0.25 \times 95{,}000 = 16{,}328.$

Divide *B*, *C*, or *D* (whichever is the least) by *A*, and the quotient will be the efficiency of a single-riveted lap joint as shown in figure below.

$$\frac{12{,}890\ (B)}{22{,}343\ (A)} = 0.576 = \text{efficiency of joint.}$$

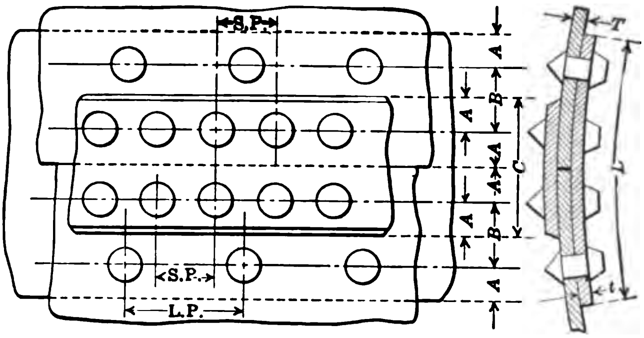


FIG. 144.—Double-riveted double butt-strap joint.

Double-riveted Double Butt-strap Joint

Thickness plate "T," inches	Diam. of cold rivet, inches	Max. diam. of rivet hole, inches	Long pitch of rivets "L.P.," inches	Short pitch of rivets "S.P.," inches	Gage "A," inches	Space "B," inches	Width of outside strap, "C," inches	Width of inside strap, "D," inches	Thickness of "t" straps, inches	Efficiency, per cent
1/4	5/8	11/16	4	2	1 1/16	2 1/8	4 1/4	8 1/2	1/4	82.8
9/32	5/8	11/16	4	2	1 1/16	2 1/8	4 1/4	8 1/2	1/4	82.8
5/16	3/4	13/16	4 1/2	2 1/4	1 1/4	2 7/16	5	9 7/8	9/32	81.9
11/32	3/4	13/16	4 1/2	2 1/4	1 1/4	2 7/16	5	9 7/8	9/32	81.9
3/8*	3/4	13/16	4 1/2	2 1/4	1 1/4	2 7/16	5	9 7/8	5/16	81.9
13/32	3/4	13/16	4 1/2	2 1/4	1 1/4	2 7/16	5	9 7/8	5/16	81.9
7/16	7/8	15/16	5	2 1/2	1 7/16	2 3/4	5 3/4	11 1/4	3/8	81.3
15/32	7/8	15/16	5	2 1/2	1 7/16	2 3/4	5 3/4	11 1/4	3/8	81.3
1/2	7/8	15/16	5	2 1/2	1 7/16	2 3/4	5 3/4	11 1/4	7/16	81.3
17/32	7/8	13/16	4 7/8	2 7/16	1 7/16	2 3/4	5 3/4	11 1/4	15/32	80.8
9/16	7/8	15/16	4 7/8	2 7/16	1 7/16	2 3/4	5 3/4	11 1/4	1/2	80.8
19/32	1	1 1/16	5 1/2	2 3/4	1 5/8	3 5/16	6 1/2	12 7/8	17/32	80.7
5/8	1	1 1/16	5 1/2	2 3/4	1 5/8	3 5/16	6 1/2	12 7/8	9/16	80.7
21/32	1	1 1/16	5 1/2	2 3/4	1 5/8	3 3/16	6 1/2	12 7/8	19/32	80.6
11/16	1	1 1/16	5 1/2	2 3/4	1 5/8	3 3/16	6 1/2	12 7/8	5/8	80.1
3/4	1 1/8	1 5/16	6 3/16	3 3/32	1 3/4	3 9/16	7	14 1/8	5/8	80.7
13/16	1 1/8	1 3/16	6 1/4	3 1/8	1 3/4	3 9/16	7	14 1/8	11/16	79.5
7/8	1 1/4	1 5/16	6 13/16	3 13/32	2	4	8	16	3/4	79.6
15/16	1 1/4	1 3/16	6 13/16	3 13/32	2	4	8	16	13/16	78.4
1	1 1/4	1 5/16	6 13/16	3 13/32	2	4	8	16	27/32	77.3

Bolts.—Of the bolts used in refinery practice the standard machine bolt is by far the most frequently employed. With hexagon nuts it is used in large numbers for bolting together flanged condenser pipe, and with modified square-shouldered head as a still neck bolt. Machine bolts are threaded according to the U. S. or Seller's standard. Tables of sizes, dimensions, and weights are given on the next page.

Set, cap, and machine screws in general, such as enter into the construction of the various classes of machinery incident to a refinery, follow no common standard,[1] in regard to threading, a fact which should be borne in mind when ordering duplicates.

[1] U. S. standard with many variations in threads per inch; the Whitworth, A. S. M. E. and S. A. E. systems are all employed.

Rivet Dimensions

Thickness of plate, "T," inches	Diameter of cold rivet, inches	Maximum diameter of rivet hole, inches	Long pitch "L.P.," inches	Short pitch "S.P.," inches	Gage "A," inches	Space "B," inches	Space "C," inches	Width of outside strap, "D," inches	Width of inside strap "E," inches	Thickness of straps, "t," inches	Efficiency in per cent
1/4	3/4	13/16	5 1/4	2 5/8	1 1/16	1 1/4	2 1/4	7 1/2	12	1/4	87.5
9/32	3/4	13/16	5 1/4	2 5/8	1 1/16	1 1/4	2 1/4	7 1/2	12	1/4	87.5
5/16	3/4	13/16	6 1/4	3 1/8	1 1/8	1 1/4	2 5/16	8 1/2	13 1/2	9/32	87.5
11/32	3/4	13/16	6 1/4	3 1/8	1 1/8	1 1/4	2 5/16	8 1/2	13 1/2	9/32	87.5
3/8	3/4	13/16	7	3 1/2	1 1/8	1 1/4	2 5/16	8 1/2	13 1/2	5/16	88.4
13/32	3/4	13/16	7	3 1/2	1 1/8	1 1/4	2 5/16	8 1/2	13 1/2	5/16	88.4
7/16	3/4	13/16	7 1/2	3 3/4	1 5/16	2	2 1/2	9 1/2	15 1/2	3/8	87.9
15/32	3/4	13/16	7 1/2	3 3/4	1 5/16	2	2 1/2	9 1/2	15 1/2	3/8	87.9
1/2	3/4	13/16	8	4	1 5/16	2	2 1/2	9 1/2	15 1/2	7/16	88.3
17/32	3/4	13/16	8	4	1 5/16	2	2 1/2	9 1/2	15 1/2	7/16	88.3
9/16	1	1 1/16	8	4	1 1/2	2 1/4	3	11	17	7/16	86.7
19/32	1	1 1/16	8	4	1 1/2	2 1/4	3	11	17	1/2	86.7
5/8	1	1 1/16	8	4	1 1/2	2 1/4	3	11	17	1/2	86.7
21/32	1	1 1/16	8	4	1 1/2	2 1/4	3	11	17	1/2	86.7
11/16	1 1/8	1 3/16	8 1/4	4 1/8	1 11/16	2 1/4	3 1/4	12	18 1/2	1/2	85.6
23/32	1 1/8	1 3/16	8 1/4	4 1/8	1 11/16	2 1/4	3 1/4	12	18 1/2	1/2	85.6
3/4	1 1/8	1 3/16	8 1/4	4 1/8	1 11/16	2 1/4	3 1/4	12	18 1/2	1/2	85.5
25/32	1 1/8	1 3/16	8 3/4	4 3/8	2	2 1/4	3 1/2	13 1/2	20 1/2	9/16	84.6
13/16	1 1/8	1 3/16	8 3/4	4 3/8	2	2 1/4	3 1/2	13 1/2	20 1/2	9/16	84.6
27/32	1 1/8	1 3/16	8 3/4	4 3/8	2	2 1/4	3 1/2	13 1/2	20 1/2	9/16	84.2
7/8	1 1/8	1 3/16	8 3/4	4 3/8	2	2 1/4	3 1/2	13 1/2	20 1/2	5/8	84.1
29/32	1 1/8	1 3/16	8 3/4	4 3/8	2	2 1/4	3 1/2	13 1/2	20 1/2	5/8	83.6
15/16	1 1/8	1 3/16	9	4 1/2	2	2 1/4	3 1/2	13 1/2	20 1/2	11/16	83.7
31/32	1 1/8	1 3/16	9	4 1/2	2	2 1/4	3 1/2	13 1/2	20 1/2	11/16	83.2
1	1 1/8	1 3/16	9 1/4	4 5/8	2 1/16	2 1/4	3 1/2	14 1/2	22	5/8	83.4
1 1/32	1 1/8	1 3/16	9 1/4	4 5/8	2 1/16	2 1/4	3 1/2	14 1/2	22	11/16	83.0
1 1/16	1 1/8	1 3/16	9 1/4	4 5/8	2 1/16	2 1/4	3 1/2	14 1/2	22	11/16	82.6
1 3/32	1 1/8	1 3/16	9 1/4	4 5/8	2 1/16	2 1/4	3 1/2	14 1/2	22	11/16	82.2
1 1/8	1 1/4	1 5/16	10	5	2 1/4	2 1/4	4 1/4	15	24 1/2	11/16	82.2

Dimensions of Screw Threads, Sellers or U. S. Standard

Bolts and Threads						Nuts and Bolt Heads				
Diameter of bolt	Threads per inch	Diameter of root of thread	Width of flat	Area of bolt body in square inches	Area of root of thread in square inches	Short diameter, hexagon and square	Long diameter, hexagon	Long diameter, square	Thickness, nut	Thickness, head
Inches		Inches	Inches			Inches	Inches	Inches	Inches	Inches
1/4	20	0.185	0.0062	0.049	0.027	1/2	0.578	0.707	1/4	1/4
5/16	18	0.240	0.0069	0.077	0.045	19/32	0.686	0.840	5/16	19/64
3/8	16	0.294	0.0078	0.110	0.068	11/16	0.794	0.972	3/8	11/32
7/16	14	0.345	0.0089	0.150	0.093	25/32	0.902	1.105	7/16	25/64
1/2	13	0.400	0.0096	0.196	0.126	7/8	1.011	1.237	1/2	7/16
9/16	12	0.454	0.0104	0.249	0.162	31/32	1.119	1.370	9/16	31/64
5/8	11	0.507	0.0113	0.307	0.202	1 1/16	1.227	1.502	5/8	17/32
3/4	10	0.620	0.0125	0.442	0.302	1 1/4	1.444	1.768	3/4	5/8
7/8	9	0.731	0.0139	0.601	0.420	1 7/16	1.660	2.033	7/8	23/32
1	8	0.837	0.0156	0.785	0.550	1 5/8	1.877	2.298	1	13/16
1 1/8	7	0.939	0.0178	0.994	0.694	1 13/16	2.093	2.563	1 1/8	29/32
1 1/4	7	1.065	0.0178	1.227	0.891	2	2.310	2.828	1 1/4	1
1 3/8	6	1.160	0.0208	1.485	1.057	2 3/16	2.527	3.093	1 3/8	1 3/32
1 1/2	6	1.284	0.0208	1.767	1.295	2 3/8	2.743	3.358	1 1/2	1 3/16
1 5/8	5 1/2	1.389	0.0227	2.074	1.515	2 9/16	2.960	3.623	1 5/8	1 9/32
1 3/4	5	1.491	0.0250	2.405	1.746	2 3/4	3.176	3.889	1 3/4	1 3/8
1 7/8	5	1.616	0.0250	2.761	2.051	2 15/16	3.393	4.154	1 7/8	1 15/32
2	4 1/2	1.712	0.0278	3.142	2.302	3 1/8	3.609	4.419	2	1 9/16
2 1/4	4 1/2	1.962	0.0278	3.976	3.023	3 1/2	4.043	4.949	2 1/4	1 3/4
2 1/2	4	2.176	0.0312	4.909	3.719	3 7/8	4.476	5.479	2 1/2	1 15/16
2 3/4	4	2.426	0.0312	5.940	4.622	4 1/4	4.909	6.010	2 3/4	2 1/8
3	3 1/2	2.629	0.0357	7.069	5.428	4 5/8	5.342	6.540	3	2 5/16
3 1/4	3 1/2	2.879	0.0357	8.296	6.510	5	5.775	7.070	3 1/4	2 1/2
3 1/2	3 1/4	3.100	0.0384	9.621	7.548	5 3/8	6.208	7.600	3 1/2	2 11/16
3 3/4	3	3.317	0.0417	11.045	8.641	5 3/4	6.641	8.131	3 3/4	2 7/8
4	3	3.567	0.0417	12.566	9.993	6 1/8	7.074	8.661	4	3 1/16
4 1/4	2 7/8	3.798	0.0435	14.186	11.328	6 1/2	7.508	9.191	4 1/4	3 1/4
4 1/2	2 3/4	4.028	0.0454	15.904	12.743	6 7/8	7.941	9.721	4 1/2	3 7/16
4 3/4	2 5/8	4.256	0.0476	17.721	14.250	7 1/4	8.374	10.252	4 3/4	3 5/8
5	2 1/2	4.480	0.0500	19.635	15.763	7 5/8	8.807	10.782	5	3 13/16
5 1/4	2 1/2	4.730	0.0500	21.648	17.572	8	9.240	11.312	5 1/4	4
5 1/2	2 3/8	4.95[illegible]	0.0526	23.758	19.267	8 3/8	9.673	11.842	5 1/2	4 3/16
5 3/4	2 3/8	5.203	0.0526	25.967	21.262	8 3/4	10.106	12.373	5 3/4	4 3/8
6	2 1/4	5.423	0.0555	28.274	23.098	9 1/8	10.539	12.903	6	4 9/16

Approximate Weight of Machine Bolts per 100, Square Heads and Square Nuts

(Hoopes & Townsend, Philadelphia, 1914)

Length under head to point, inches	Diameter												
	1/4 in.	3/8 in.	7/16 in.	1/2 in.	9/16 in.	5/8 in.	3/4 in.	7/8 in.	1 in.	1 1/4 in.	1 1/2 in.	1 3/4 in.	2 in.
1 1/4	3.1	8.4	12.5	17.7	24.3	30.7	50.4						
1 1/2	3.4	9.2	13.6	19.1	26.0	32.8	53.5						
2	4.1	10.8	15.7	21.8	29.5	37.1	59.7	89.4	125.7				
2 1/2	4.8	12.3	17.8	24.6	33.0	41.4	65.9	97.3	136.8	246.3			
3	5.5	13.8	19.9	27.4	36.5	45.7	72.1	105.7	147.8	263.5	470		
3 1/2	6.2	15.3	21.8	29.8	40.0	50.0	78.3	114.2	158.9	280.8	495		
4	6.9	16.9	24.0	32.6	43.5	54.4	84.5	122.6	169.9	298.1	520	720	
4 1/2	7.5	18.4	26.1	35.4	46.7	58.3	90.3	130.5	179.4	314.1	545	753	
5	8.2	19.9	28.2	38.1	50.2	62.6	96.5	138.9	190.4	331.4	570	786	1180
5 1/2	8.9	21.5	30.3	40.9	53.7	66.9	102.7	147.4	201.5	348.6	595	820	1225
6	9.6	23.0	32.4	43.7	57.2	71.3	108.9	155.8	212.5	365.9	620	854	1270
6 1/2	10.3	24.6	34.5	46.4	60.7	75.6	115.1	164.3	223.6	383.1	645	888	1315
7	11.0	26.1	36.6	49.2	64.2	79.9	121.3	172.7	234.6	400.4	670	922	1360
7 1/2	11.7	27.7	38.8	51.9	67.6	84.2	127.6	181.2	245.6	417.7	695	956	1405
8	12.4	29.2	40.9	54.7	71.1	88.5	133.8	189.6	256.7	434.9	725	990	1450
9	13.7	32.4	44.9	60.0	77.8	96.8	145.7	205.9	278.0	468.2	775	1058	1540
10	15.1	35.5	49.1	65.5	84.8	105.4	158.2	222.8	300.0	502.7	825	1126	1630
11	16.5	38.6	53.4	71.0	91.8	114.1	170.6	239.8	322.2	537.3	875	1194	1720
12	17.9	41.7	57.6	76.5	98.8	122.7	183.0	256.7	344.3	571.8	925	1262	1810
13	19.3	44.8	61.8	82.0	105.5	131.0	195.4	273.6	366.3	606.3	975	1330	1900
14	20.6	47.9	66.0	87.6	112.5	139.6	207.9	290.5	388.4	640.8	1025	1398	1990
15	22.0	51.0	70.3	93.1	119.5	148.2	220.3	307.4	410.5	675.3	1075	1468	2080
16	23.4	54.1	74.5	98.6	126.4	156.9	232.7	324.3	432.6	709.8	1125	1536	2170
17	24.8	57.2	78.7	104.1	133.4	165.5	245.1	341.2	454.7	744.3	1175	1604	2260
18	26.2	60.3	82.9	109.7	140.4	174.1	257.6	358.1	476.8	778.9	1225	1672	2350
20	28.9	66.5	91.4	120.7	154.4	191.4	282.4	392.0	521.0	847.9	1325	1808	2530
22	31.7	72.7	99.9	131.7	168.4	208.6	307.3	425.8	565.1	916.9	1425	1944	2710
24	34.4	78.9	108.3	142.8	182.4	225.9	332.1	459.6	609.3	986.0	1525	2080	2890
26	37.2	85.2	116.8	153.8	196.3	243.1	357.0	493.4	653.5	1055.0	1625	2216	3070
28	40.0	91.4	125.2	164.9	210.3	260.4	381.8	527.3	697.7	1124.0	1725	2352	3250
30	42.7	97.6	133.7	175.9	224.3	277.7	406.7	561.1	741.9	1193.0	1825	2488	3450

Weight per 100 nuts

Square..	0.7	2.5	3.9	5.7	8.1	9.9	16.8	26.9	40.1	77.8	162	257	381
Hexagon	0.6	2.1	3.2	4.8	6.7	8.3	14.0	22.3	33.4	64.0	134	207	307
Diff...	0.1	0.4	0.7	0.9	1.4	1.6	2.8	4.6	6.7	13.8	28	50	74

Weight of 100 heads

Square..	0.8	2.4	4.0	5.9	8.8	11.4	20.0	31.4	44.9	90.9	144	231	345
Hexagon	0.7	2.2	3.5	5.3	7.9	10.3	17.0	28.2	39.4	83.9	132	215	302
Diff...	0.1	0.2	0.5	0.6	0.9	1.1	3.0	3.2	5.5	7.0	12	16	43

For weight of bolts with hexagonal heads and hexagonal nuts

Subtract	0.2	0.6	1.2	1.5	2.3	2.7	5.8	7.8	12.2	20.8	40	66	117

Chain.—Outside of special elevator, link and drive chains, obviously beyond the scope of this volume, a refinery uses considerable quantities of standard coil or cable chain for falls, swing pipes, etc. Dimensions and weights of the common standard types are listed as follows:

Proof Coil or Cable Chain

Size chain, inches	Number links per foot	O.D. length, inches	O.D. width, inches	Approximate weight, 100 feet	Proof test	Approximate breaking point
3/16	13 1/2	1 3/8	7/8	46	1,000	2,000
1/4	12 1/2	1 1/2	1 1/16	75	1,500	3,300
5/16	11	1 7/8	1 1/4	110	2,600	5,200
3/8	10	2 1/8	1 1/2	155	3,600	7,200
7/16	9	2 1/4	1 11/16	200	4,500	10,000
1/2	8	2 1/2	1 7/8	260	6,500	13,000
9/16	7 1/2	2 7/8	2 1/8	325	8,000	16,000
5/8	6 1/2	3 3/8	2 1/4	400	9,500	20,000
3/4	6	3 7/8	2 11/16	590	13,500	28,000
7/8	5	4 3/8	3 1/8	800	18,500	39,000
1	4	5	3 5/8	1000	24,000	51,500
1 1/8	3 3/4	5 1/2	4	1300	29,000	60,000
1 1/4	3 3/8	6 1/8	4 3/8	1500	39,000	80,000

Wire.—Wire is much employed in refinery construction, from its initial use in connection with cement forms to guy cables and fences, to say nothing of nails, screws, etc. Its products may be found listed in any catalogue of hardware, and need not be further discussed; but as some confusion exists as to systems of gages employed, it may be well to mention that many manufacturers use the American Steel and Wire Company (formerly Washburn and Moen) gage for soft iron or steel wire, and the Stubs steel-wire gage for products of tool steel, such as drill stock, etc. A slight modification of the Stubs steel-wire gage is known as the twist-drill and steel-wire gage or Moen standard, and is used by American manufacturers not adopting the Stubs gage. To increase the confusion there is another Stubs gage, known as the Stubs iron-wire gage, identical with the B.W.G. gage, and also known as the Old English gage. It is adopted by many manufacturers as a standard, not for iron or steel, but for copper, brass, and bronze wire for woven wire cloth and screen. Wire for electrical purposes is generally based on the B. and S. (American Wire), or on the Edison or Circular Mil gage, the former not to be confounded with the American Steel and Wire (Washburn and Moen) gage. The B.W.G. (Old English), Stubs (iron wire), B. and S. (American Wire), and The American Steel and Wire (Washburn and Moen) gages are compared in the table of standard gages.[1] Equivalents of the other systems mentioned now follow.

[1] See p. 773.

Edison, or Circular Mil Gage for Electrical Wires

Gage number	Circular mils.	Diameter in mils.	Gage number	Circular mils.	Diameter in mils.	Gage number	Circular mils.	Diameter in mils.
3	3,000	54.78	70	70,000	264.58	190	190,000	435.89
5	5,000	70.72	75	75,000	273.87	200	200,000	447.22
8	8,000	89.45	80	80,000	282.85	220	220,000	469.05
12	12,000	109.55	85	85,000	291.55	240	240,000	489.90
15	15,000	122.48	90	90,000	300.00	260	260,000	509.91
20	20,000	141.43	95	95,000	308.23	280	280,000	529.16
25	25,000	158.12	100	100,000	316.23	300	300,000	547.73
30	30,000	173.21	110	110,000	331.67	320	320,000	565.69
35	35,000	187.09	120	120,000	346.42	340	340,000	583.10
40	40,000	200.00	130	130,000	360.56	360	360,000	600.00
45	45,000	212.14	140	140,000	374.17			
50	50,000	223.61	150	150,000	387.30			
55	55,000	234.53	160	160,000	400.00			
60	60,000	244.95	170	170,000	412.32			
65	65,000	254.96	180	180,000	424.27			

Twist Drill and Steel Wire Gage

(MORSE)

(Manufacturers' Standard)

No.	Size, inch	No.	Size, inch	No.	Size, inch	No.	Size, inch	No.	Size, inch	No.	Size, inch
1	0.2280	14	0.1820	27	0.1440	40	0.0980	53	0.0595	67	0.0320
2	.2210	15	.1800	28	.1405	41	.0960	54	.0550	68	.0310
3	.2130	16	.1770	29	.1360	42	.0935	55	.0520	69	.0292
4	.2090	17	.1730	30	.1285	43	.0890	56	.0465	70	.0280
5	.2055	18	.1695	31	.1200	44	.0860	57	.0430	71	.0260
6	.2040	19	.1660	32	.1160	45	.0820	58	.0420	72	.0250
7	.2010	20	.1610	33	.1130	46	.0810	59	.0410	73	.0240
8	.1990	21	.1590	34	.1110	47	.0785	60	.0400	74	.0225
9	.1960	22	.1570	35	.1100	48	.0760	61	.0390	75	.0210
10	.1935	23	.1540	36	.1065	49	.0730	62	.0380	76	.0200
11	.1910	24	.1520	37	.1040	50	.0700	63	.0370	77	.0180
12	.1890	25	.1495	38	.1015	51	.0670	64	.0360	78	.0160
13	.1850	26	.1470	39	.0995	52	.0635	65	.0350	79	.0145
								66	.0330	80	.0135

Stubs Steel Wire Gage

(For Nos. 1 to 50 see table on page 774)

No.	Size, inch	No.	Size, inch	No.	Size, inch	No.	Size, inch	No.	Size, inch	No.	Size, inch
Z	0.413	P	0.323	F	0.257	51	0.066	61	0.038	71	0.026
Y	.404	O	.316	E	.250	52	.063	62	.037	72	.024
X	.397	N	.302	D	.246	53	.058	63	.036	73	.023
W	.386	M	.295	C	.242	54	.055	64	.035	74	.022
V	.377	L	.290	B	.238	55	.050	65	.033	75	.020
U	.368	K	.281	A	.234	56	.045	66	.032	76	.018
T	.358	J	.277	1	See	57	.042	67	.031	77	.016
S	.348	I	.272	to	page	58	.041	68	.030	78	.015
R	.339	H	.266	50	774	59	.040	69	.029	79	.014
Q	.332	G	.261			60	.039	70	.027	80	.013

Miscellaneous forged items.—Under this classification may be included many special articles of pressed manufacture such as nozzles, manholes, crabs, lugs and flanges, as well as cold-rolled key steel, shafting, etc. Lack of space prevents description of any of these except flanges, which are shown in tank, boiler, and marine types. The first is for light tank service, the second for heavy pumping-out lines, etc., while the marine weight is suitable for high pressures at elevated temperatures.

Forged-steel Tank Flanges

Nominal size, inches	Outside diameter	Thickness	Depth of hub	Diameter of hub	Approximate weight, pounds
1	5	3/16	11/16	1 7/8	1 1/2
1 1/4	5 1/2	1/4	11/16	2 3/16	2
1 1/2	6	1/4	3/4	2 9/16	2 1/4
2	6 1/2	1/4	3/4	3 1/16	3
2 1/2	7 1/2	3/16	1	3 9/16	4 1/2
3	8	3/16	1 1/8	4 5/16	5
3 1/2	8 1/2	5/16	1 1/8	4 13/16	7
4	9 1/2	3/8	1 3/16	5 3/8	7 1/4
4 1/2	10	3/8	1 1/4	5 7/8	8
5	11	3/8	1 5/16	6 3/16	11 1/2
6	12	3/8	1 3/8	7 11/16	14 1/2

Forged-steel Boiler Flanges

Size pipe, inches	Diameter, inches	Thickness, inches	Depth hub, inches	Approximate weight, pounds	Size pipe, inches	Diameter, inches	Thickness, inches	Depth hub, inches	Approximate weight, pounds
3/4	6	5/16	1	3	4 1/2	10 1/2	1/2	2	15
1	6	5/16	1	4	5	11 1/2	1/2	2	17
1 1/4	6 1/2	5/16	1	4 1/2	6	12 1/2	1/2	2	22
1 1/2	7	3/8	1 1/4	5	7	14	5/8	2 1/2	29
2	8	3/8	1 1/4	7	8	15	5/8	2 1/2	36
2 1/2	8 1/2	3/8	1 1/2	8	9	16	3/4	2 1/2	43
3	9	3/8	1 1/2	9	10	17 1/2	3/4	2 1/2	51
3 1/2	9 1/2	7/16	1 1/2	10	12	20	13/16	2 1/2	71
4	10	7/16	2	13					

Iron castings.—Iron castings are widely used in the building of refineries, in special shapes as furnace and boiler fronts, nozzles, mannecks, still lugs, etc., and in well-recognized standard forms as grate bars, cast-iron pipe, valves, and fittings. Cast-iron pipe is employed as low-pressure class A (100-foot head) bell-and-spigot type with lead-caulked joints, for low-pressure water mains, occasionally for sewer purposes; as standard flanged pipe for water service and manifold connections; and extensively in somewhat heavier weight flanged units for condenser pipe. For the last purpose,

Forged-steel Marine Flanges

Size, inches	Diameter, inches	Thickness, inches	Depth of hub, inches	Approximate weight, pounds
1½	7	½	1⅜	6
2	8	½	1½	7
2½	8½	½	1⅝	8
3	9	$\frac{9}{16}$	1⅝	10
3½	9½	$\frac{9}{16}$	1¾	11½
4	11	$\frac{11}{16}$	2¼	20
4½	11½	¾	2⅜	23
5	12½	¾	2¾	30
6	13½	¾	3	35

different refiners specify different weights and thicknesses. One table has already been included in the section on Standard Apparatus Design,[1] selection of weights employed depending on individual preference as the result of experience in corrosive action of distillate, high sulphur-bearing oils naturally requiring a heavier weight pipe than those free from this deleterious element. A widely used form of cast-iron pipe for condenser service is the Universal, manufactured in 6-foot lengths with ground seat joints requiring only two bolts for joining sections, as against the standard number in flanged types. Such pipe, on account of its conical type of joint, can be laid somewhat out of line if desired, so that it also finds use as a water-supply pipe in place of the slower-fitted bell and spigot form. Tables of standard cast-iron pipe appear below.

Standard Thickness and Weights of Cast-iron Pipe

Nominal inside diameter, inches	Class A, 100-foot Head, 43-pound Pressure			Class B, 200-foot Head, 86-pound Pressure		
	Thickness, inches	Pounds per		Thickness, inches	Pounds per	
		Feet	Length		Feet	Length
3	0.39	14.5	175	0.42	16.2	194
4	.42	20.0	240	.45	21.7	260
6	.44	30.8	370	.48	33.3	400
8	.46	42.9	515	.51	47.5	570
10	.50	57.1	685	.57	63.8	765
12	.54	72.5	870	.62	82.1	985
14	.57	89.6	1075	.66	102.5	1230
16	.60	108.3	1300	.70	125.0	1500
18	.64	129.2	1550	.75	150.0	1800
20	.67	150.0	1800	.80	175.0	2100

[1] See p. 180.

Quantity of Lead Required for Cast-iron Pipe Bell and Spigot Joints

Diameter, inches	Depth of Joint			
	2 inches	2¼ inches	2½ inches	Solid
	Approximate weight of lead in joint, pounds			
3	6.00	6.50	7.00	10.25
4	7.50	8.00	8.75	13.00
6	10.25	11.25	12.25	18.00
8	13.25	14.50	15.75	23.00
10	16.00	17.50	19.00	31.00
12	19.00	20.50	22.50	36.50
14	22.00	24.00	26.00	38.50
16	30.00	33.00	35.75	64.75
18	33.80	36.90	40.00	72.00
20	37.00	40.50	44.00	80.00

Universal Cast-iron Ground Joint Pipe [1]

Standard 6-foot length

Nominal inside diameter, inches	Class No. 100, 100 Pounds Pressure,			Class No. 130, 130 Pounds Pressure,		
	Approximate thickness, inches	Estimated weight, Pounds per		Approximate thickness, inches	Estimated weight, Pounds per	
		Foot	6-foot length		Foot	6-foot length
2						
3						
4	0.37	18	108	0.40	18¾	112½
6	.43	30	180	.45	31	186
8	.47	44¼	265½	.49	46	276
10	.50	60½	363	.53	63½	381
12	.53	75½	453	.57	80½	483
14	.56	94½	567	.60	99½	597
16	.60	115½	693	.65	123	738

[1] Universal Cast-Iron Pipe Co., Chicago, Ill., Standard.

Cast-iron Flanged Pipe

Standard 12-foot lengths

Inside diameter of pipe, inches	Weight per Lineal Foot, Exclusive of Flanges																	Weight of each flange
	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16	
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
3	10.2	12.5	14.9	17.3	19.8	22.4	25.1	27.8	30.7	33.6	......	......	......	......	......	......	......	7.25
4	......	16.2	19.2	22.3	25.4	28.6	31.9	35.3	38.7	42.2	......	......	......	......	......	......	......	12.50
5	......	19.8	23.3	27.0	30.7	34.5	38.4	42.4	46.4	50.5	54.7	......	......	......	......	......	......	14.37
6	......	......	27.9	32.2	36.6	41.0	45.5	50.1	54.8	59.6	64.4	69.4	......	......	......	......	......	17.40
8	......	......	36.6	42.1	47.7	53.4	59.2	65.0	70.9	77.0	83.0	89.2	......	......	......	......	......	27.24
10	......	......	......	52.0	58.9	65.8	72.8	79.9	87.1	91.3	101.6	109.0	116.5	124.0	......	......	......	41.03
12	......	......	......	......	70.0	78.2	86.4	94.8	103.2	111.7	120.2	128.8	137.6	146.4	......	......	......	55.54
14	......	......	......	......	81.2	90.6	100.1	109.6	119.3	129.0	138.8	148.7	158.6	168.7	178.8	......	......	68.98
16	......	......	......	......	......	103.0	113.7	124.5	135.4	146.4	157.4	168.5	179.7	191.0	202.3	......	......	87.20
18	......	......	......	......	......	......	127.3	139.4	151.5	163.7	176.0	188.3	200.8	213.3	225.9	238.5	......	96.29
20	......	......	......	......	......	......	141.0	154.3	167.6	181.1	194.6	208.2	221.8	235.6	249.4	263.3	......	123.09

Cast-iron fittings, while replaced by welding to a certain extent, are still largely used, those made by each manufacturer (apart from flanged fittings) having slightly different standards of weight, thickness, etc., but all falling under one of five classes; (a), low pressure, up to 25 pounds; standard, up to 125 pounds; medium, 125-175 pounds; extra heavy, 175-250 pounds; and hydraulic for pressures up to 800 pounds per square inch.

Cast-iron fittings in screwed form (Briggs Standard) are usually stocked in sizes from ¼ inch to 12 inches in ordinary cast-iron grade, and in sizes from ¼ inch to 8 inches in malleable style, larger sizes in both grades being readily obtainable at short notice. Malleable fittings in sizes up to 1 inch are used in refinery construction principally for small air, water, gas, and steam lines; in sizes from 1 inch to 8 inches in various ells, tees, and return bends subjected to severe expansion stresses; and in ordinary cast-iron grade in all sizes from ¾ inch up for low-pressure steam, water, oil and vapor lines. Flanged fittings are made in all sizes from 1¼ inches up, their employment in refinery practice being generally limited to condenser coils, receiving and distributing manifolds, agitator outlets, etc.; although they are occasionally used in steam and water service. Flanged fittings have the advantage of being practically standardized in manufacture, the product of one factory being readily substituted for that of another, as far as dimensions between faces, number of bolt holes, etc., are concerned. Valves are made in both screwed and flanged pattern with cast-iron bodies (brass mounted) from 2 inches, in some cases from 1 inch up, in globe, cross, and gate patterns. Globe valves are used in steam, gas and air control in sizes up to 3 inches, while gate valves are employed for liquids from the smallest to the largest sizes, and also commonly for steam, gas, and air in units over 2 inches.

Cross valves, generally in flanged form, are much used in manifold construction together with cast-iron cocks. Railing fittings, light screwed fittings of malleable type, are employed in handrails, machine guards, etc., while recessed drain fittings find application for waste-pipe installations in refinery office buildings and laboratories.

Standard weight fittings are the most frequently used in refinery construction in general steam, water, gas, oil, and vapor-line service; extra heavy fittings in connecting still flow and pumping-out lines, or where service is generally severe within limits of recommended working pressure; while medium malleable-weight fittings can be advantageously installed for steam pressures commonly employed in refineries in lines above 4 inches where standard cast-iron fittings are near their safe working limit. Hydraulic (and ammonia) fittings are used only in wax-plant service or for other severe duty. In listing fittings, the run of a tee is first given, then the branch, while all fittings with laterals or ends of different sizes, such as reducing ells, tees, etc., are grouped according to the largest opening. To make any attempt to include a complete list of the dimensions, weights, etc., of the fittings and valves used around a refinery would be entirely beyond the limits of this volume. The appended tables, pages 278–279, however, cover the more commonly used units, the reader being referred to the various manufacturers of such supplies for more detailed information.

General Dimensions of Standard and Extra Heavy Fittings (Flange) *

A = distance center to face, varying for long radius and 45° ells from standard value for ells and tees.

Dimensions of fittings up to 16 inches are governed by the size of the largest opening. For example, a 12-inch by 12-inch by 16-inch tee will have the same dimensions as a 16-inch by 16-inch by 16-inch tee.

For flange dimensions and bolt data consult the table of Standard and Extra Heavy Companion Flanges on page 280.

* Crane Co., Chicago, Ills., standards.

General Dimensions of Standard, Extra Heavy, and Hydraulic Fittings (Screwed) *

A = distance center to face, ells and tees. *B* = distance center to face, 45° ell.
C = distance between end and face, cap. *D* = distance between faces, reducer.†
E = distance between faces, lip union.

Size		Fittings, *A*	45° ells, *B*	Caps, *C*	Reducers, *D*	Lip unions, *E*
1/8	Standard	....	....	....	....	....
1/4	Standard X. H. H.	13/16 1 1/16	3/4 3/4	....	....	2 1/4 ....
3/8	Standard X. H. H.	15/16 1 1/4	13/16 7/8	....	.... 1 1/16	2 7/16 ....
1/2	Standard X. H. H.	1 1/8 1 3/8	7/8 1	....	....	2 11/16 ....
3/4	Standard X. H. H.	1 5/16 1 5/8	1 1 1/4	....	.... 1 5/8	3 1/16 ....
1	Standard X. H. X. H. H.	1 7/16 2 2	1 1/8 1 3/8 1 5/16	....	 2	3 5/16 ....
1 1/4	Standard X. H. X. H. H.	1 3/4 2 1/4 2 1/4	1 5/16 1 1/2 1 1/2	....	2 1/4 .... 2 5/8	3 11/16 ....
1 1/2	Standard X. H. X. H. H.	1 15/16 2 9/16 2 1/2	1 7/16 1 5/8 1 13/16	....	2 1/4 .... 2 13/16	4 ....
2	Standard X. H. X. H. H.	2 1/4 3 3	1 11/16 1 13/16 2	....	2 7/16 .... 3 5/16	4 5/16 ....
2 1/2	Standard X. H. X. H. H.	2 13/16 3 1/2 3 1/2	1 13/16 2 1/4 2 1/4	....	2 13/16	4 1/2 ....
3	Standard X. H. X. H. H.	3 1/4 4 1/4 4 1/4	2 5/16 2 1/2 2 1/2	....	2 15/16	....
3 1/2	Standard X. H. X. H. H.	3 7/16 4 13/16 4 3/4	2 1/4 2 9/16 2 3/4	....	3 1/4	Standard & Railroad Unions with Male and Female ends
4	Standard X. H. X. H. H.	3 3/4 5 1/4 5 1/4	2 1/2 2 3/4 2 15/16	2 1/16	3 5/8	
4 1/2	Standard X. H. X. H. H.	4 1/16 5 1/2 5 5/8	2 11/16 3	2 5/16	3 5/8	
5	Standard X. H. X. H. H.	4 7/16 6 1/4 6 1/4	3 1/16 3 5/16	2 5/8	3 3/4	
6	Standard X. H. X. H. H.	5 1/8 7 1/4 7 1/4	3 7/16 3 3/4	2 5/8	4 5/8	
7	Standard X. H.	5 13/16 8 1/4	3 7/8 4	2 7/8	4 13/16	
8	Standard X. H.	6 1/2 9 1/4	4 1/4 4 3/4	3 1/8	5 1/4	
9	Standard	7 5/16	4 11/16	3 1/8	5 11/16	
10	Standard X. H.	7 7/8 11 3/8	5 5/16 4 7/8	3 3/8	6 5/16	
12	Standard X. H.	9 1/4 13 3/8	6 5 1/2	4 1/8	7 1/4	

* Crane Company, Chicago, Ill., standards.
† Reducers are listed according to size of large opening, smaller being next receding size shown in table.

Dimensions of Standard and Extra Heavy Fittings

Size		1¼	1½	2	2½	3	3½	4	4½	5	6	7
Dimension "A," center to face	Standard	3¾	4	4½	5	5½	6	6½	7	7½	8	8½
	X. H.	4¼	4½	5	5½	6	6½	7	7½	8	8½	9
Center to face, long radius ells	Standard	5½	6	6½	7	7¾	8½	9	9½	10¼	11½	12¾
	*X. H.	5½	6	6½	7	7¾	8½	9	9½	10¼	11½	12¾
Radius, long radius ells	Standard	.....	.....	.....	.....	.....	.....	7⅝	7¾	8½	9⅝	10⅞
	X. H.	.....	.....	5¼	5⅝	6¼	6⅞	7⅝	7¾	8½	9⅝	10⅞
Center to face, 45° ells	Standard	2	2¼	2½	3	3	3½	4	4	4½	5	5½
	X. H.	2½	2¾	3	3½	3½	4	4½	4½	5	5½	6

Size		8	9	10	12	14	15	16	18	20	22	24
Dimension "A," center to face	Standard	9	10	11	12	14	14½	15	16½	18	20	22
	X. H.	10	10½	11½	13	15	15½	16½	18	19½	20½	22½
Center to face, long radius ells	Standard	14	15¼	16½	19	21½	22¾	24	26½	29	31½	34
	X. H.	14	15¼	16½	19	21½	22¾	24	26½	29	31½	34
Radius, long radius ells	Standard	12	13	14¼	16½	18⅜	20	21¼	23⅝	26	28⅝	30¾
	X. H.	12	13	14¼	16½	18⅜	20	21¼	23⅝	26	28⅝	30¾
Center to face, 45° ells	Standard	5½	6	6½	7½	7½	8	8	8½	9½	10	11
	X. H.	6	6½	7	8	8½	9	9½	10	10½	11	12

* Crane Company, Chicago, Ill., standards.

Steel castings.—These are employed in ferro- or semi-steel, or in all-steel grades as standard valves, fittings, etc., for high-pressure service. They are generally for use at elevated temperatures about pressure stills. Special semi- or cast-steel flanges, stuffing boxes, manheads, etc., can also be made to order at short notice, but attention is called to the fact that a semi-steel casting, unless the composition is definitely specified, may be practically cast iron with all the inherent weakness of the latter. In other words, semi-steel may contain from 3 to 25 per cent of cast steel; hence the need of caution in purchase and use. All steel castings should be minutely examined for blow holes and flaws, it being apparently difficult to obtain a perfect cored casting, so that forged steel items should be used in their stead wherever possible.

Miscellaneous metals.—Of metals other than iron or steel, lead, copper, brass, aluminum, etc., all find employment in refinery practice. Copper is used principally for wire, commutator segments, bus-bars, etc., in various types of electrical equipment. Lead is used in sheet form for agitator lining, in acid-restoring plants and in hardened alloy as babbitt, acid valves, etc. Brass and bronze are used for standard pump, and all the smaller globe and gate valves, as well as the trimmings of the larger units, to say nothing of the special so-called acid-resisting brass and bronze valves of larger sizes. Phosphor bronze forms the bearings of many pump and machine shafts, while babbitt is extensively used in practically all journal boxes. Aluminum is employed in certain machine castings, zinc is used as a sheathing metal, while a variety of proprietary composition metals such as Monel, Atterite, Duriron, etc., are obtainable,

General Dimensions of Standard and Extra Heavy Companion Flanges *

Size		3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5	6
Diameter of flange	Standard	3 1/2	4	4 1/2	5	6	7	7 1/2	8 1/2	9	9 1/4	10	11
	X. H.	.....	4 1/2	5	6	6 1/2	7 1/2	8 1/4	9	10	10 1/2	11	12 1/2
Thickness of flange	Standard	7/16	7/16	1/2	9/16	5/8	11/16	3/4	13/16	15/16	15/16	15/16	1
	X. H.	.....	11/16	3/4	13/16	7/8	1	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8	1 7/16
Diameter of hub	Standard	1 1/4	1 15/16	2 5/16	2 5/8	3 1/4	3 5/8	4 5/16	4 3/4	5 3/8	5 15/16	6 7/16	7 7/16
	X. H.	.....	2 1/16	2 1/2	2 7/8	3 9/16	4	4 5/8	5 1/4	5 3/4	6 5/16	6 3/4	7 13/16
Length of thread	Standard	5/8	11/16	3/4	7/8	1	1 1/16	1 1/8	1 3/16	1 3/16	1 1/4	1 5/16	1 7/16
	X. H.	.....	1	1 1/8	1 1/4	1 3/8	1 3/16	1 7/16	1 5/8	1 3/4	1 13/16	1 7/8	2
Diameter bolt circle	Standard	2 5/8	3	3 3/8	3 7/8	4 3/4	5 1/2	6	7	7 1/2	7 3/4	8 1/2	9 1/2
	X. H.	.....	3 1/4	3 3/4	4 1/2	5	5 7/8	6 5/8	7 1/4	7 7/8	8 1/2	9 1/4	10 5/8
Number of bolts	Standard	4	4	4	4	4	4	4	4	8	8	8	8
	X. H.	.....	4	4	4	4	4	8	8	8	8	8	12
Size of bolts	Standard	3/8	7/16	7/16	1/2	5/8	5/8	5/8	5/8	5/8	3/4	3/4	3/4
	X. H.	.....	1/2	1/2	5/8	5/8	3/4	3/4	3/4	3/4	3/4	3/4	3/4
Length of bolts	Standard	1 1/2	1 1/2	1 1/2	1 3/4	2	2 1/4	2 1/2	2 1/2	2 3/4	2 3/4	2 3/4	3
	X. H.	.....	2	2 1/4	2 1/2	2 1/2	3	3 1/4	3 1/4	3 1/2	3 1/2	3 3/4	3 3/4
Diameter bolt holes	Standard	1/2	9/16	9/16	5/8	3/4	3/4	3/4	3/4	3/4	7/8	7/8	7/8
	X. H.	.....	5/8	5/8	3/4	3/4	7/8	7/8	7/8	7/8	7/8	7/8	7/8

Size		7	8	9	10	12	14	15	16	18	20	22	24
Diameter of flange	Standard	12 1/2	13 1/2	15	16	19	21	22 1/4	23 1/2	25	27 1/2	29 1/2	32
	X. H.	14	15	16 1/4	17 1/2	20 1/2	23	24 1/2	25 1/2	28	30 1/2	33	36
Thickness of flange	Standard	1 1/16	1 1/8	1 1/8	1 3/16	1 1/4	1 3/8	1 3/8	1 7/16	1 9/16	1 11/16	1 13/16	1 7/8
	X. H.	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/8	2 3/16	2 1/4	2 3/8	2 1/2	2 5/8	2 3/4
Diameter of hub	Standard	8 5/8	9 11/16	10 3/4	11 15/16	14 1/8	15 7/16	16 1/16	17 1/2	19 9/16	21 3/4	23 3/4	26
	X. H.	9	10 1/4	11 5/16	12 5/8	14 5/8	15 3/4	16 13/16	18	20 1/4	22 5/16	24 1/2	26 3/4
Length of thread	Standard	1 1/2	1 5/8	1 3/4	1 7/8	2 1/16	2 3/16	2 3/16	2 1/16	2 3/8	2 3/4	2 7/8	3
	X. H.	2 1/16	2 3/16	2 1/4	2 3/8	2 9/16	2 11/16	2 13/16	2 7/8	3 1/16	3 1/4	3 7/16	3 5/8
Diameter bolt circle	Standard	10 3/4	11 3/4	13 1/4	14 1/4	17	18 3/4	20	21 1/4	22 3/4	25	27 1/4	29 1/2
	X. H.	11 3/4	13	14	15 1/4	17 3/4	20 1/4	21 1/2	22 1/2	24 3/4	27	29 1/4	32
Number of bolts	Standard	8	8	12	12	12	12	16	16	16	20	20	20
	X. H.	12	12	12	16	16	20	20	20	24	24	24	24
Size of bolts	Standard	3/4	3/4	3/4	7/8	7/8	1	1	1	1 1/8	1 1/8	1 1/4	1 1/4
	X. H.	7/8	7/8	1	1	1 1/8	1 1/4	1 1/4	1 1/4	1 1/4	1 3/8	1 1/2	1 5/8
Length of bolts	Standard	3	3 1/4	3 1/4	3 1/2	3 1/2	4	4	4	4 1/2	4 3/4	5	5 1/4
	X. H.	4	4 1/4	4 1/2	5	5 1/4	5 1/2	5 3/4	6	6 1/4	6 1/2	7	7 1/2
Diameter bolt holes	Standard	7/8	7/8	7/8	1	1	1 1/8	1 1/8	1 1/8	1 1/4	1 1/4	1 3/8	1 3/8
	X. H.	1	1	1 1/8	1 1/8	1 1/4	1 1/4	1 3/8	1 3/8	1 3/8	1 3/8	1 5/8	1 3/4

* Crane Company, Chicago, Ill., standards.

certain superior properties of strength, resistance to corrosion, or some equally advantageous feature being claimed for each. Space does not permit further details, other than the table of weights immediately following:

Non-Ferrous Metals and Alloys Used in Refinery Construction

Substance	Specific gravity	Weight, pounds per cubic foot	Use
Aluminum, cast-hammered...	2.6–2.8	165	Special castings
Brass, cast-rolled...........	8.4–8.7	534	Valve bodies, valve disks, pump rods, etc.
Copper, cast-rolled.........	8.8–9.0	556	Wire, commutator, and bus-bars
Lead......................	11.6	710	Agitator lining, acid concentrating pans, pipe, etc.
Monel metal...............	8.8–9.0	556	Valve disks, plugs, rods, etc.
Platinum..................	21.1–21.5	1330	Laboratory utensils, acid restoring pans, hoods
Tin, cast-hammered........	7.2–7.5	459	Coating for steel sheets (tin-plate)
Zinc, cast-rolled............	6.9–7.2	440	Coating steel plate (galvanized iron)

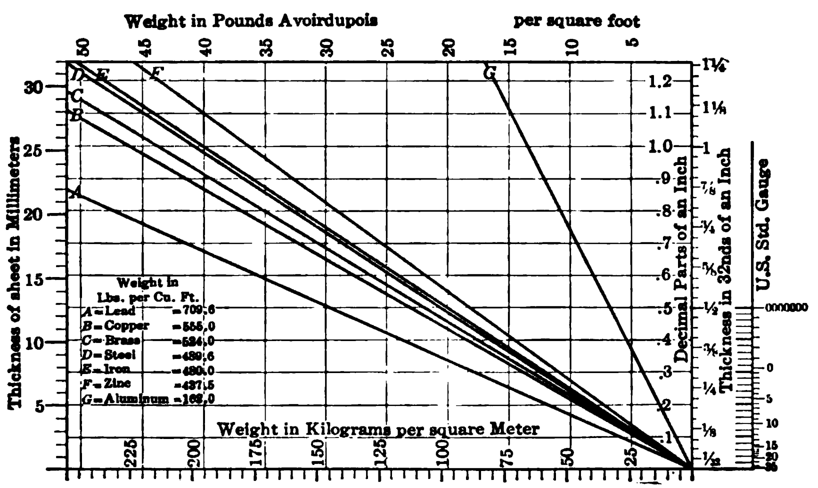


FIG. 145.—Curves showing weights of various metals.

By use of the curves above, Fig. 145, the weights of various metals in sheet form may also be quickly derived from their thickness or gage.

Weight of Rolled Sheet Metals

Insulating materials.—As the term is used in refineries, insulating materials may be classified according to employment, as:

(1) Low temperatures (wax plant).
- *a.* Cork; blocks, sectional pipe covering, granulated.
- *b.* Wool; matted felt, sectional pipe covering.
- *c.* Hair felt; matted.
- *d.* Diatomaceous earth; blocks, bricks.

(2) Medium temperatures (steam lines, boilers, and stills).
- *a.* Carbonate of magnesia; blocks, sectional pipe covering, cement.
- *b.* Asbestos; sheets, sectional pipe covering, cement.
- *c.* Diatomaceous earth; blocks, sectional pipe covering, cement.
- *d.* Miscellaneous powdered or shredded material.
- *e.* Hair and waste silk felts.

(3) High temperatures.
- *a.* Diatomaceous earth; blocks, brick, cement.
- *b.* Dry powdered material.

With reference to the first division, cork in the form of 2- or 4-inch pressed board (granulated in inaccessible spaces) is by far the most used for the insulation of press-vault walls, brine coolers, cold settling tanks, etc., diatomaceous earth bricks, also finding application. Sectional cork pipe covering, hair and wool felts are each employed for brine-line covering.

Concerning the second classification, the blocks, sectional coverings, and cements noted under "*a*," "*b*," and "*c*" vary sufficiently in insulating power, price, and wearing quality to make selection a matter of individual judgment, the heat insulating values that occur in a subsequent table serving only as a general guide. Where the purchase of any large amount of covering is contemplated, tests should be carried out with various makes as nearly as possible under service conditions. The class "*d*" substances, of which asbestos fiber may be taken as a typical example, are generally of relatively poor insulating value, and should only be employed where expansion and exposure to severe conditions is required, as in caulking material between stills and upper brick courses, etc., etc. Hair and waste-silk felts possess high insulating value. But they char, or rather crumble, after long exposure, even at steam temperatures corresponding to 125 pounds pressure. Consequently where they are employed several thicknesses of asbestos paper or fire felt should be first applied and the hair or waste-silk felt itself should be protected with a final covering of tar paper. In fact the life of all insulation on outside lines can be greatly lengthened by wrapping with protective paper and occasionally painting to render it waterproof. Radiation losses from uninsulated hot surfaces, which can be reduced from 60 per cent to 90 per cent by proper insulation, are tabulated on the next page.

With respect to the final division, the loss in B.t.u., from highly heated metal surfaces (pressure stills) is shown by the last values in the tabulation, while an inspection of the chart (Fig. 146) will show the great heat dissipation through uninsulated brick walls.

Temperature A = initial fire-brick temperature, insulated setting.

Mean fire-brick temperature = mean fire-brick temperature insulated setting.

Temperature A_1 = initial fire-brick temperature uninsulated setting.

Mean fire-brick temperature$_1$ = mean fire-brick temperature uninsulated setting.

Silocel insulating brick temperature = mean silocel brick temperature insulated setting.

Heat Losses from Uninsulated Hot Surfaces

(Temperatures lower than 212° F.)

Steam pressure (gage), pounds	Surface temperature (degrees F.)	Difference between surface temperature and surrounding air (degrees F.)	Heat loss per square foot per hour (B.t.u.)	Waste of 22°–24° * Bé. fuel oil in gallons per square foot per year
....	100	30	56.6	5
....	120	50	97.5	9
....	140	70	142.0	12
....	160	90	190.0	17
....	180	110	242.0	21
....	200	130	298.5	26
(Ordinary steam temperatures)				
0	212	142	334.0	29*
10	240	170	425.0	37
25	267	197	522.5	46
50	298	228	644.0	56
75	320	250	737.5	65
100	338	268	820.0	72
150	366	296	960.0	84
200	388	318	1079.0	95
250	406	336	1184.0	104
(Ordinary still temperatures)				
....	240	70	480	83†
....	280	210	640	110
....	320	250	820	141
....	360	290	1020	175
....	400	330	1240	213
....	440	370	1480	255
....	480	410	1740	299
....	520	450	2020	347
....	560	490	2320	399
....	600	530	2640	454

* The above figures involving radiation losses and waste of oil are based on the following: (*a*) temperature of surrounding air 70° F.; (*b*) 13,300 B.t.u. available per pound of 22°–24° Bé. gravity fuel oil, or 101,479 B.t.u. per gallon, which is equivalent to a boiler efficiency of 70 per cent, using fuel oil with an assumed heat value of about 19,000 B.t.u. per pound.

† The above figures involving radiation losses and waste of oil are based on the following: (*a*) Temperature of surrounding air 70° F.; (*b*) 6650 B.t.u. available per pound of 22°–24° Bé. gravity fuel oil, or 50,740 B.t.u. per gallon, which is equivalent to a still efficiency of 35 per cent, using fuel oil with an assumed heat value of about 19,000 B.t.u. per pound.

Temperature B = final red brick temperature insulated setting.

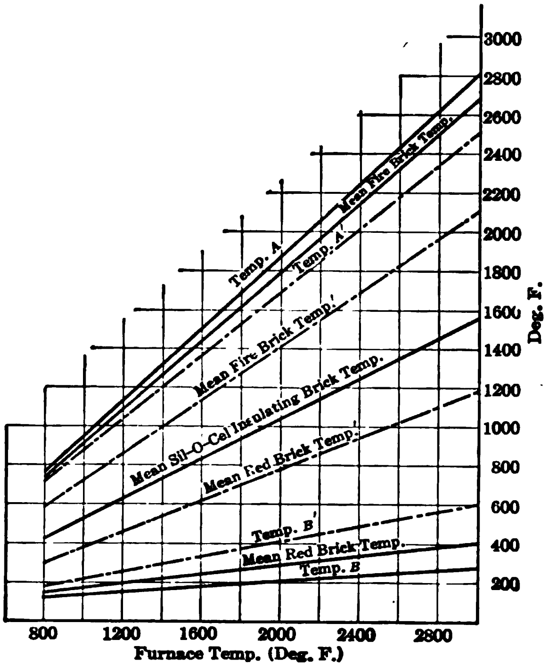


FIG. 146.—Dissipation values. Celite Products Company, New York, N. Y.

Mean red brick temperature = mean red brick temperature insulated setting.

Temperature B_1 = final red brick temperature uninsulated setting.

Mean red brick temperature$_1$ = mean red brick temperature uninsulated setting.

Obviously, only materials capable of withstanding high temperatures can be employed for this last class of insulation, diatomaceous earth with varying quantities of asbestos fiber and magnesia forming in general the main content of such insulators. They are made up in flat and curved blocks, standard brick sizes, and sectional covering. When used in brick form courses they are laid between fire and red brick, or occasionally on the outside of the latter. The latter construction is more commonly used for low-temperature insulation where these bricks are also employed.

While, as stated, actual tests under service conditions may be very profitably made on insulating covering before purchase, in lieu of such tests, the following tables will prove of value:

Table of Relative Value of Non-conducting Materials

Substance	Value	Substance	Value
Hair or wool felt	1.00	Gas-house carbon	0.47
Mineral wool	0.68–0.83	Asbestos paper	0.47
Diatomaceous earth	0.66–0.79	Paste, diatomaceous earth and asbestos	0.47
Carbonate magnesia	0.67–0.76	Asbestos fiber	0.36
Wood charcoal	0.63–0.75	Plaster of paris, dry	0.34
Paper	0.50–0.74	Clay, with vegetable fiber	0.34
Cork	0.71	Anthracite coal, powder	0.29
Sawdust	0.61–0.68	Coke, in lumps	0.27
Paste, diatomaceous earth and hair	0.63	Air space, undivided	0.14–0.22
Wood, cross grade	0.40–0.55	Baked clay, brick	0.07
Loam, dry and open	0.55	Glass	0.05
Chalk, ground	0.51	Stone	0.02
Coal ashes	0.35–0.49		

From the above it will be noted that air space alone is one of the poorest non-conductors, though the best owe their efficiency to the numerous minute air cells in their structure. Substances of high refractory value, such as asbestos fiber, clay, etc., are, it will be seen, very poor insulators in themselves; but when such substances are properly felted with other substances, the resultant product is often of high efficiency, as will be noted in the tables of tests made on commercial coverings.

Condensation Tests of Commercial Coverings *

Kind of covering	Steam pressure	Air temperature	Ounces of water condensed per hour
H. W. Johns-Manville Co. (85 per cent magnesia)	69.6	75.6	34.7
Keasbey and Mattison Co. (85 per cent magnesia)	69.5	72.4	42.1
National air cell (1¾-inch)	69.1	71.1	45.0
H. W. Johns-Manville asbestos-sponge felt	69.6	75.6	40.6
H. W. Johns-Manville asbestos roll fire-felt (⅜-inch) and asbestos-sponge felt (1½-inch)	73.1	68.4	33.7
Two-ply remanit (waste-silk fiber)	73.1	68.4	33.7
J. M. air cell (fireproof)	72.8	71.0	50.9
H. W. Johns-Manville asbestocel (2-inch)	72.8	71.0	33.5
Built-up layer three thicknesses asbestos paper, 1-inch standard hair felt, two layers tar paper	72.7	75.5	30.7
Bare pipe	72.7	75.5	214.0

* The above tests were conducted by the writer some years ago on a 15-foot section of 4-inch pipe with the various coverings listed, they being of standard thickness unless otherwise mentioned. Steam was maintained at as near 70 pounds as was practicable, each individual test was of eight hours' duration. Water was drawn every hour, The values in table are averages for the test period.

Another test [1] made on a larger scale with 200 feet of 2-inch pipe, electrically heated to a constant temperature, was covered with the different materials, and the heat radiated by each covering was determined by measuring the current required to keep the pipe at a constant temperature. The table on the next page is a condensed statement of the results with the temperature of the pipe corresponding to 160 pounds steam pressure.

Packing.—This is one of the most widely used items in refinery practice, and may be classified as follows:

1. Sheet packing.
    a. Compressed asbestos composition.
    b. Woven or reinforced asbestos cloth.
    c. Rubber composition.
    d. Rubber, cloth inserted.
    e. Paper, mill board.
    f. Sheet metal.

[1] For further details of this interesting test consult Kent's Mechanical Engineers' Pocketbook, p. 585.

Heat Loss from a Pipe Covered with Varying Insulation

No.	Covering	Average thick-ness	B.t.u. loss per minute per square foot at 160-pound pressure	B.t.u. per square foot per hour per degree difference of tem-perature	Per cent heat saved by cover-ing
2	Solid cork	1.68	1.672	0.348	87.1
3	85 per cent magnesia	1.18	2.008	0.418	84.5
4	Solid cork	1.20	2.048	0.427	84.2
5	85 per cent magnesia	1.19	2.130	0.444	83.6
6	Laminated asbestos cork	1.48	2.123	0.442	83.7
7	85 per cent magnesia	1.12	2.190	0.456	83.2
8	Asbestos air cell (indent)	1.26	2.333	0.486	83.1
9	Asbestos sponge felted	1.24	2.552	0.532	80.3
10	Asbestos air cell (long)	1.70	2.750	0.573	78.8
11	"Asbestoscel" (radial)	1.22	2.801	0.584	78.5
12	Asbestos air cell (long)	1.29	2.812	0.586	78.4
15	"Remanit" (silk) wrapped	1.51	1.452	0.302	88.8
16	85 per cent magnesia, 2-inch sectional and ½ inch block	2.71	1.381	0.288	89.4
17	85 per cent magnesia, 2-inch sectional and ½ inch plaster	2.45	1.387	0.289	88.7
18	85 per cent magnesia, two 1-inch sectional	2.50	1.412	0.294	89.0
19	85 per cent magnesia, two 1-inch sectional	2.24	1.465	0.305	88.7
20	85 per cent magnesia, 2-inch sectional	2.34	1.555	0.324	88.0
21	85 per cent magnesia, 2-inch sectional	2.20	1.568	0.314	87.9
	Bare pipe (from outside tests)	....	13	2.708	

2. Rod packing.
   a. Braided asbestos and cotton fabric, rubber composition.
   r. Braided or twisted asbestos.
   c. Braided or twisted flax, rubber composition.
   d. Braided or twisted flax.
   e. Laminated duck, rubber composition, hydraulic.
   f. Metallic.

With respect to sheet packing, grade "a" may be used for moderate and high-pressure steam gasket service, as well as for ordinary oil-pumping lines. Grade "b" may be advantageously employed as boiler and still-neck gaskets, in wire reinforced form as gas-and-oil engine cylinder-head gaskets, and when encased in copper or steel for high temperature and pressure oil lines, manheads, etc. Packing containing more than a minimum rubber friction, "c," is best adapted for low and moderate pressure steam and should not be used on oil lines. In general, a so-called rubber oilproof sheet

processed to the extent of being only slightly attacked by oil, has lost its wearing qualities, and is not recommended. Soft slightly vulcanized sheet rubber, next to metallic lead, forms one of the best gaskets for acid service. Cheap cloth-inserted packing should only be used for low-pressure work, where the joint cannot blow out, as in tank tar-outlet caps, etc. Paper, of the ordinary building variety, may be successfully employed for smoothly-faced filter and still necks, while ordinary mill board forms a cheap ideal gasket for flanged condenser fittings. Sheet metal in the form of lead is used to a certain extent for acid service, and copper for gas- and oil-engine cylinder heads. The latter requires very smooth surfaces for successful application.

Rod packing in various forms of grade "a" is used for general steam and fluid service, "b" for high-pressure steam, air compressors, and fluids attacking rubber; while "c" finds employment as a general hot- or cold-water packing. Grade "d" is used where rubber is not permissible, as in pistons of gasoline pumps, hydraulic and general cold-water service, and "e" for piston-packed pumps, ammonia and general high-pressure fluid pumping. Metallic packing "f," either composed of soft composition metal, or in the more usual form of some standard packing wrapped with an antifriction metallic or copper foil, finds its principal application in high-pressure and (copper wrapped) high-temperature service; although it may be employed to advantage in a large majority of situations where standard packing is used, provided it be installed when the rod is new and that proper lubrication is maintained.

Prime generators of power.—These may be listed in the order of their importance as follows: (*a*), steam boilers, (*b*), gas or oil engines, and (*c*), purchased electrical current. Practically all refineries produce their own steam, which forms the only source of power in a majority of plants. Those of small capacity usually employ steam in direct form, not only in the process, but in steam pumps, steam blowers, etc., with a minimum of power transformed mechanically through the agency of a small steam engine, which in turn may drive a generator for lighting purposes. Plants of somewhat larger or medium size, operate as a rule with more profit by using direct steam only in the process, transforming that portion needed for power through the agency of a modern steam engine or turbine, and utilizing the exhaust for heating purposes. Medium to large plants, or, in general, plants covering considerable acreage, find additional operating profit in a second transformation of mechanical power into electrical energy, and the distribution of the latter to the required points. This class of plants, especially in localities where gas is cheap, or the crude refined is of low grade, may find it more advantageous to operate on low-pressure steam for the process, and install an oil or gas engine for primal mechanical power. Under certain circumstances, gas engines can be run profitably by waste refinery gases, either taken direct from the stills (after the removal of liquid condensates) or manufactured from waste tars or other unsalable by-products. Wherever gas or oil engines are installed, however, it should always be remembered that their exhaust cannot be utilized like that from the turbine, for instance, where only a reduction in steam pressure takes place without an appreciable lowering of temperature. Plants located near cheap centers of electrical power, or on high-tension lines, may sometimes find that it is to their advantage to purchase primal energy direct, outside of that required for process when investment and continuity of service are considered. Steam may be used direct, or a portion of its energy may be transposed into mechanical or electrical channels for needed power purposes; such power may also be produced by a gas or oil engine, or electrical current may be purchased from outside sources. The choice between these methods depends on the size of the plant, the extent of refining, local conditions, available capital, and many interrelating features, a thorough understanding of which requires operating experience and close engineering study.

The subject of steam boilers is so well covered in standard engineering treatises

that only certain salient features will be discussed. First, it should be noted that the term horse-power, as applied to boiler capacity, is not equivalent to the definite unit of 33,000 foot-pounds per minute, but is commonly held to mean the evaporation of 30 pounds of water per hour at 100° F. into steam at 70 pounds pressure above the atmosphere. In other words a 150 H.P. boiler should be capable of evaporating 4500 pounds (150×30) of water per hour at 100° F. into steam at 70 pounds gage pressure. While a boiler of such rated capacity may actually achieve such a result under ideal circumstances, 70 per cent of the rated capacity should be figured as the power more apt to be developed under average working conditions. A purchase contract for a boiler should specify its leading dimensions and rated capacity, and where a specific guarantee is made the operating conditions under which the guarantee is to be met should be clearly set forth, for example such as steam pressure, kind of fuel, force of the draft, duration of test, etc. This test, incidentally, should not be a matter of hours but preferably of days, so that general working conditions may be established. In general, a 70 per cent rating for a boiler of reputable manufacture will take care of operating contingencies such as inferior fuel, lack of proper attendance, and sudden demand; lowering of pressure (generally possible in refinery practice without serious detriment to process if warning is given in time) will allow temporary peak loads not figured in the 70 per cent value to be carried. The unit of evaporation used in expressing test results is 34.5 pounds of water per hour from and at 212° F. which it should be pointed out, may be a considerably higher figure than the actual evaporation obtained, especially if the feed water is of a moderate temperature.

While space does not permit the discussion of the general rules regarding boiler construction, those pertaining to stresses developed in the shell are of sufficient interest to deserve mention, as applying equally to acid blow cases, air receivers, pressure stills, etc., as follows:

Shells [1]

The thickness of shell for a given pressure is found from the common formula for safe strength of thin cylinders:

$$P = 2tTf \div dF; \quad \text{whence } t = PdF \div 2Tf.$$

P = safe working pressure; T = tensile strength of plate, both in pounds per square inch; t = thickness of plate in inches; f = ratio of the strength of a riveted joint to that of the solid plate; F = factor of safety allowed; and d = diameter of shell or drum in inches.

The value taken for T is commonly that stamped on the plates by the manufacturer, f is taken from tables of strength of riveted joints or is computed, and F must be taken at a figure not less than is prescribed by local or State laws, or, in the case of marine boilers, by the rules of the U. S. Board of Supervising Inspectors, and may be more than this figure if a greater margin of safety is desired.

Strength of circumferential seam.—Safe working pressure $P = 4tTf \div dF$; $t = PdF \div 4Tf$, notation as above. The strength of a shell against rupture on a circumferential line is twice that against rupture on a longitudinal line, therefore single riveting is sufficient on the circumferential seams while double, triple or quadruple riveting is used for the longitudinal seams.

Thickness of plates; riveting.—(Mass. Boiler Rules, 1910). The longitudinal joints of a boiler, the shell or drum of which exceeds 36 inches diameter, shall be of butt and double-strap construction; if it does not exceed 36 inches lap-riveted construction may be used, the maximum pressure on such shells being 100 pounds per square inch.

[1] For further details concerning operation and construction of boilers consult Kent's Mechanical Engineer's Pocketbook; the publications of Babcock and Wilcox, Heine Boiler Works, etc.

Minimum thickness of plates in flat-stayed surfaces, $\frac{5}{16}$ inch.

The ends of staybolts shall be riveted over or upset.

Rivets shall be of sufficient length to completely fill the rivet holes and form a head equal in strength to the body of the rivet.

Rivets shall be machine driven wherever possible, with sufficient pressure to fill the rivet holes, and shall be allowed to cool and shrink under pressure.

Rivet holes shall be drilled full size, with plates, butt straps and heads bolted in position; or they may be punched not to exceed $\frac{1}{8}$ inch less than full size for plates over $\frac{5}{16}$ inch thick, and $\frac{1}{8}$ inch or less for plates not exceeding $\frac{5}{16}$ inch thick, and then drilled or reamed to full size with plates, butt straps and heads bolted up in position.

The longitudinal joints of horizontal return-tubular boilers shall be located above the fire-line of the setting.

The thickness of plates in a shell or drum shall be of the same gage. Minimum thickness of shell plates (Mass. Rules and A.S.M.E. Code): diameter 36 inches or under, $\frac{1}{4}$ inch; over 36 to 54 inches, $\frac{5}{16}$ inch; over 54 to 72 inches, $\frac{3}{8}$ inch; over 72 inches, $\frac{1}{2}$ inch.

Minimum thickness of butt straps:

Plates, inches.........	$\frac{1}{4}$ to $\frac{11}{32}$	$\frac{3}{8}$ to $\frac{13}{32}$	$\frac{7}{16}$ to $\frac{15}{32}$	$\frac{1}{2}$ to $\frac{9}{16}$	$\frac{5}{8}$ to $\frac{3}{4}$	$\frac{7}{8}$	1 to $1\frac{1}{8}$	$1\frac{1}{4}$
Straps, inches.........	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$

Minimum thickness of tube sheets:

Diameter of tube sheet, inches..	42 or under	Over 42 to 54	Over 54 to 72	Over 72
Thickness, inch...	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$

To ascertain heating surface in tubular boilers multiply $\frac{2}{3}$ the circumference of boiler by length of boiler in inches and add to it the area of all the tubes.

Convex or bumped heads.[1]—Minimum thickness of convex heads, $t=\frac{1}{2}d\ FP \div T$; d=diameter in inches; $F=5$=factor of safety; P=working pressure pounds per square inch; T=tensile strength stamped on the head.

When a convex head has a manhole opening, the thickness is to be increased not less than $\frac{1}{8}$ inch.

When the head is of material of the same quality and thickness as that of the shell, the head is of equal strength with the shell when the radius of curvature of the head equals the diameter of the shell, or when the rise of the curve=0.134 diameter of shell.

(The A.S.M.E. Boiler Code specifies a higher factor of safety, 5.5, and adds $\frac{1}{8}$ inch to the thickness, making the formula $t=2.75\ PR/T+\frac{1}{8}$ inch, R being the radius to which the head is dished, in inches. When R is less than $0.8d$ the thickness shall be at least that found by the formula when $R=0.8d$. Dished heads with the pressure on the convex side are allowed a maximum working pressure equal to 60 per cent of that for heads of the same dimensions with the pressure on the concave side. When the dished head has a manhole opening the thickness as found by these rules shall be increased by not less than $\frac{1}{8}$ inch. The corner radius of a dished head shall be not less than $1\frac{1}{2}$ inches nor more than 4 inches, and not less than $0.03R$. A manhole opening in a dished head shall be flanged to a depth not less than three times the thickness of the head measured from the outside.)

[1] Kent's Mechanical Engineers' Pocketbook, p. 913.

Allowable Working Pressures on Cylindrical Shells *

Diameter of shell, inches	Joint riveted	Plate Thickness in Inches																
		$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{17}{32}$	$\frac{9}{16}$†	$\frac{9}{16}$‡	$\frac{19}{32}$	$\frac{5}{8}$	$\frac{21}{32}$	$\frac{11}{16}$	$\frac{23}{32}$
24	Double...........	189.7	213.4	234.6	258.0	281.5	304.9	326.0	349.3	372.6								
30	Double...........	151.8	170.7	187.6	206.4	225.2	243.9	260.8	279.4	298.1								
36	Double...........	126.5	142.3	156.4	172.0	187.6	203.3	217.3	232.8	248.4								
	Triple............	133.6	150.3	167.1	183.8	202.5	219.4	235.0	251.7	269.8	286.6	298.0	.....	314.5	331.1	347.7	359.6	375.9
42	Double...........	108.4	121.9	134.0	147.4	160.8	174.2	186.3	199.6	212.9								
	Triple............	114.5	128.9	143.2	157.5	173.6	188.1	201.4	215.8	231.2	245.7	255.4	.....	269.6	283.8	298.0	308.2	322.2
48	Double...........	94.8	106.7	117.3	129.0	140.7	152.4	163.0	174.6	186.3								
	Triple............	100.2	112.7	125.3	137.8	151.9	164.5	176.2	188.8	202.3	215.0	223.5	.....	235.9	248.3	260.7	269.7	281.9
54	Double...........	84.3	94.8	104.2	114.6	125.1	135.5	144.9	155.2	165.6								
	Triple............	89.1	100.2	111.4	122.5	135.0	146.2	156.6	167.8	179.8	191.1	198.6	.....	209.7	220.7	231.8	239.7	250.6
60	Double...........	75.8	85.3	93.8	103.2	112.6	121.9	130.4	139.1	149.0								
	Triple............	80.2	90.2	100.2	110.2	121.5	131.6	141.0	151.0	161.8	172.0	178.8	.....	188.7	198.6	208.6	215.7	225.5
	Quadruple........	85.9	96.7	107.4	118.2	129.5	140.3	150.7	161.5	172.5	183.2	194.0†	192.6‡	203.3	214.0	224.7	233.9	244.5
66	Double...........	68.9	77.6	85.3	93.8	102.3	110.9	118.5	127.0	135.5								
	Triple............	72.9	82.0	91.1	100.2	110.5	119.7	128.1	137.3	147.1	156.3†	162.5	.....	171.6	180.6	189.6	196.1	205.0
	Quadruple........	78.1	87.9	97.7	107.4	117.7	127.5	137.0	146.8	156.8	166.6	176.4†	175.1‡	184.8	194.5	204.3	212.6	222.3
72	Double...........	63.2	71.1	78.2	86.0	93.8	101.6	108.6	116.4	124.2								
	Triple............	66.8	75.1	83.5	91.9	101.2	109.7	117.5	125.8	134.9	143.3	149.0	.....	157.2	165.5	173.8	179.8	187.9
	Quadruple........	71.6	80.6	89.5	98.5	107.9	116.9	125.5	134.6	143.7	152.7	161.7†	160.5‡	169.4	178.3	187.2	194.9	203.8
78	Triple............	61.6	69.4	77.1	84.8	93.5	101.2	108.4	116.2	124.5	132.2	137.5	.....	145.1	152.8	160.4	165.9	173.4
	Quadruple........	66.1	74.4	82.6	90.9	99.6	107.9	115.9	124.2	132.7	140.9	149.2†	148.1‡	156.4	164.6	172.8	179.9	188.1
84	Triple............	57.2	64.4	71.6	78.7	86.8	94.0	100.7	107.9	115.6	122.8	127.7	.....	134.8	141.9	149.0	154.1	161.1
	Quadruple........	61.4	69.0	76.7	84.4	92.5	100.2	107.7	115.3	123.2	130.9	138.6†	137.5‡	145.2	152.8	160.5	167.0	174.6
90	Quadruple........	57.3	64.4	71.6	78.8	86.3	93.5	100.5	107.7	115.0	122.1	129.3†	128.4‡	135.6	142.6	149.8	155.9	163.0
96	Quadruple........	53.7	60.4	67.1	73.8	80.9	87.6	94.2	100.9	107.8	114.5	121.3†	120.3‡	127.1	133.7	140.4	146.2	152.8
102	Quadruple........	50.5	56.8	63.2	69.5	76.1	82.5	88.7	95.0	101.4	107.8	114.1†	113.3‡	119.6	125.9	132.2	137.6	143.8
108	Quadruple	47.7	53.7	59.7	65.6	71.9	77.9	83.7	89.7	95.8	101.8	107.8†	107.0‡	112.9	118.9	124.8	129.9	135.8

* This table is based on tensile strength of 55,000 pounds per square inch with a factor of safety of 5 and butt strap joint efficiencies as shown on p. 268; pressures being recommended by the Hartford Steam Boiler Inspection & Insurance Company.

† Quadruple riveted joint with $\frac{15}{16}$-inch rivet holes. Eff. 94.1 per cent. ‡ Quadruple riveted joint with $1\frac{1}{16}$-inch rivet holes. Eff. 93.4 per cent

Allowable Working Pressures on Cylindrical Shells—Continued

Diameter of shell, inches	Joint riveted	Plate Thickness in Inches																
		3/4	25/32	13/16	27/32	7/8	29/32	15/16	31/32	1	1 1/32	1 1/16	1 3/32	1 1/8	1 5/32	1 3/16	1 7/32	1 1/4
36	Triple............	391.8	403.9	420.0	434.1	449.7	462.9	479.5	492.5	509.6								
42	Triple............	335.8	346.2	360.0	372.1	385.4	396.8	411.0	422.1	436.8								
48	Triple............	293.9	302.9	315.0	325.5	337.2	347.2	359.6	369.4	382.2								
54	Triple............	261.2	269.2	280.0	289.4	299.8	308.6	319.6	328.3	339.7								
60	Triple............	235.1	242.3	252.0	260.4	269.8	277.7	287.7	295.5	305.8								
	Quadruple........	254.9	264.3	274.9	284.0	292.6	300.7	309.7	317.9	330.7	338.8	346.7	354.9	363.0	370.9	381.8	389.6	397.8
66	Triple............	213.7	220.3	229.1	236.7	245.2	252.5	261.5	268.6	278.0								
	Quadruple........	231.7	240.3	249.9	258.1	266.0	273.3	281.5	289.0	300.6	308.0	315.2	322.6	330.0	337.2	347.1	354.2	361.6
72	Triple............	195.9	201.9	210.0	217.0	224.8	231.4	239.7	246.2	254.8								
	Quadruple........	212.4	220.3	229.1	236.6	243.8	250.6	258.0	264.9	275.6	282.3	288.9	295.7	302.5	309.1	318.2	324.7	331.5
78	Triple............	180.8	186.4	193.8	200.3	207.5	213.6	221.3	227.3	235.2								
	Quadruple........	196.0	203.3	211.5	218.4	225.0	231.3	238.2	244.5	254.4	260.6	266.7	273.0	279.2	285.3	293.7	299.7	306.0
84	Triple............	167.9	173.1	180.0	186.0	192.7	198.4	205.5	211.0	218.4								
	Quadruple........	182.0	188.8	196.4	202.8	209.0	214.8	221.2	227.0	236.2	242.0	247.6	253.5	259.2	264.9	272.7	278.3	284.1
90	Quadruple........	169.9	176.2	183.3	189.3	195.0	200.4	206.4	211.9	220.4	225.8	231.1	236.6	242.0	247.3	254.5	259.7	265.2
96	Quadruple........	159.3	165.2	171.8	177.5	182.8	187.9	193.5	198.6	206.7	211.7	216.7	221.8	226.8	231.8	238.6	243.5	248.6
102	Quadruple........	149.9	155.5	161.7	167.0	172.1	176.8	182.1	187.0	194.5	199.2	203.9	208.7	213.5	218.2	224.6	229.2	234.0
108	Quadruple........	141.6	146.8	152.7	157.7	162.5	167.0	172.0	176.6	183.7	188.2	192.6	197.1	201.6	206.0	212.1	216.4	221.0

Dimensions of Standard Boiler Tubes

External diameter, inches	Standard thickness, inches	Inside diameter, inches	Inside surface per foot of length	Length per square foot of inside surface	Outside surface per foot of length, square foot	Length, per square foot outside surface, feet	Internal area, square foot	External area, square foot
2	0.095	1.810	0.4738	2.110	0.5236	1.910	0.0179	0.0218
2¼	0.095	2.060	0.5393	1.854	0.5890	1.698	0.0213	0.0276
2½	0.109	2.282	0.5974	1.674	0.6545	1.528	0.0284	0.0341
2¾	0.109	2.532	0.6629	1.508	0.7199	1.389	0.0350	0.0412
3	0.109	2.782	0.7283	1.373	0.7854	1.273	0.0422	0.0491
3¼	0.120	3.010	0.7880	1.269	0.8508	1.175	0.0494	0.0576
3½	0.120	3.260	0.8535	1.172	0.9163	1.091	0.0580	0.0668
3¾	0.120	3.510	0.9189	1.088	0.9817	1.018	0.0672	0.0767
4	0.134	3.732	0.9770	1.024	1.0472	0.955	0.0760	0.0873

Feed water heaters and economizers.—All exhaust steam produced from pumps, engines, turbines, etc., that cannot be advantageously used for heating or employed in process, should be absorbed by a feed-water heater, preferably of open type. It is generally possible to further utilize the hot condenser overflow and in this way secure additional economy, but as much as is practicable of the condensed water present in the exhaust should also be returned to the system, not only on account of its B.t.u. content, but because of its purity. With the minimum back pressure customarily carried in an exhaust system, it is obviously only possible to heat feed-water to a temperature equivalent to or slightly above 212° F. Larger plants sometimes find it a paying proposition to install economizers heated by waste heat gases, thus still further increasing the temperature of the boiler feed. These are matters to be worked out from several angles, investment, quantity of waste heat available, size of plant, etc.; and require close engineering study. The accompanying tables show the economies that may be effected by the use of heated feed water subject to the foregoing modifying influences.

An approximate rule for the conditions of ordinary practice is, that a saving of 1 per cent is made by each increase of 11° F. in the temperature of the feed-water. This corresponds to 0.0909 per cent per degree.

The calculation of saving is made as follows: boiler-pressure, 100 pounds gage; total heat in steam above 32° F. = 1185 B.t.u. Feed-water, original temperature 60° F.; final temperature 209° F. Increase in heat-units, 150.

Superheaters.—Superheater installations for refinery service are generally of doubtful economy, inasmuch as but a minimum of steam is usually employed for power purposes. Modern practice has demonstrated that low-pressure steam is suitable for most processes. It is more or less a problem of fuel efficiencies of stills versus boilers. Where considerable steam is used for power purposes, or where it must be transmitted a long distance, superheaters directly after boilers or occasionally at detached points, may be of advantage. Local conditions and causes previously discussed govern such installations. Apparent economies effected by the use of superheating saturated steam 100° F. are shown below.

Feed-water Heaters

Percentage of saving for each degree of increase in temperature of feed water heated by waste steam.

Initial temperature of feed	Steam Pressure in Boiler, Pounds per Square Inch above Atmosphere											Initial temperature of feed
	0	20	40	60	80	100	120	140	160	180	200	
32°	0.0872	0.0861	0.0855	0.0851	0.0847	0.0844	0.0841	0.0839	0.0837	0.0835	0.0833	32°
40	.0878	.0867	.0861	.0856	.0853	.0850	.0847	.0845	.0843	.0841	.0839	40
50	.0886	.0875	.0868	.0864	.0860	.0857	.0854	.0852	.0850	.0848	.0846	50
60	.0894	.0883	.0876	.0872	.0867	.0864	.0862	.0859	.0856	.0855	.0853	60
70	.0902	.0890	.0884	.0879	.0875	.0872	.0869	.0867	.0864	.0862	.0860	70
80	.0910	.0898	.0891	.0887	.0883	.0879	.0877	.0874	.0872	.0870	.0868	80
90	.0919	.0907	.0900	.0895	.0888	.0887	.0884	.0883	.0879	.0877	.0875	90
100	.0927	.0915	.0908	.0903	.0899	.0895	.0892	.0890	.0887	.0885	.0883	100
110	.0936	.0923	.0916	.0911	.0907	.0903	.0900	.0898	.0895	.0893	.0891	110
120	.0945	.0932	.0925	.0919	.0915	.0911	.0908	.0906	.0903	.0901	.0899	120
130	.0954	.0941	.0934	.0928	.0924	.0920	.0917	.0914	.0912	.0909	.0907	130
140	.0963	.0950	.0943	.0937	.0932	.0929	.0925	.0923	.0920	.0918	.0916	140
150	.0973	.0959	.0951	.0946	.0941	.0937	.0934	.0931	.0929	.0926	.0924	150
160	.0982	.0968	.0961	.0955	.0950	.0946	.0943	.0940	.0937	.0935	.0933	160
170	.0992	.0978	.0970	.0964	.0959	.0955	.0952	.0949	.0946	.0944	.0941	170
180	.1002	.0988	.0981	.0973	.0969	.0965	.0961	.0958	.0955	.0953	.0951	180
190	.1012	.0998	.0989	.0983	.0978	.0974	.0971	.0968	.0964	.0962	.0960	190
200	.1022	.1008	.0999	.0993	.0988	.0984	.0980	.0977	.0974	.0972	.0969	200
210	.1033	.1018	.1009	.1003	.0998	.0994	.0990	.0987	.0984	.0981	.0979	210
220	......	.1029	.1019	.1013	.1008	.1004	.1000	.0997	.0994	.0991	.0989	220
230	......	.1039	.1031	.1024	.1018	.1012	.1010	.1007	.1003	.1001	.0999	230
240	......	.1050	.1041	.1034	.1029	.1024	.1020	.1017	.1014	.1011	.1009	240
250	......	.1062	.1052	.1045	.1040	.1035	.1031	.1027	.1025	.1022	.1019	250

Steam turbines..................10 per cent.
Simple engines.......18 per cent, and over.

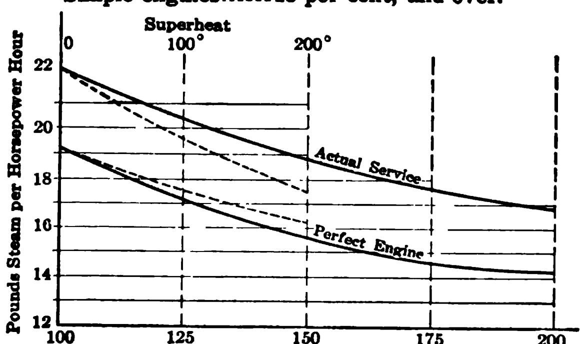


FIG. 147.—Curve showing apparent economies effected by the use of superheating saturated steam at 100° F.

Steam engines.—The simple slide-valve steam engine is well known; its use is only justifiable for intermittent loads in small plants. Continuous service demands at least a high-speed automatic-cut-off valve engine where a saving of 10 to 15 per cent of steam may be effected over the simple slide-valve type. Inasmuch as the economies obtained by the steam turbine equal those of the steam engine for moderate sizes, and

surpass the latter in larger units to say nothing of the cumbersome bulk of an engine of large horse-power, the force of the above remarks is apparent. The formula for engine horse-power for a single-cylinder double-acting steam engine is:

$$\text{H.P.} = \frac{P \times L \times A \times N \times F}{33,000},$$

where P = gage pressure at engine;
L = length of stroke in feet;
A = area of piston in square inches;
N = number of strokes per minute;
F = factor of cut-off;
= .599 for $\frac{1}{4}$ cut-off;
= .670 for $\frac{1}{3}$ cut-off.

Operating economies for various types of steam engines in comparison with other forms of power producers are shown in Fig. 147.

Turbines.—With plants using considerable power distributed over a wide area, where gas or direct internal-combustion engines are not available, the steam turbine in connnection with an electrical generator forms a highly efficient and flexible means of power distribution. It is assumed that the turbine exhaust can be utilized to advantage in the process, or for heating feed water. The absolute economy of the turbine itself is relatively unimportant. From a general standpoint, a turbine operating under 35 pounds back pressure, for instance, is more economical where its exhaust steam can be used directly in the refining process, than a unit operating under 10 pounds back pressure, with the exhaust employed to heat feed water where the system requires additional high-pressure steam for the process.

Internal combustion engines.—Where cheap gas is obtainable, or the plant operates on low-grade crude with a maximum demand for mechanical power, either a gas, crude-oil (gas-oil), or fuel-oil engine finds best application. These engines are manufactured both in four- and two-cycle types. In the former three strokes of the piston are required to successively expel burned gases, draw in a fresh supply of combustible mixture of gas and air, compress the latter into small space in the combustion chamber and thus prepare the charge for the explosion or power stroke of the fourth cycle. The two-cycle engine gives an impulse to the piston for each revolution of the crank shaft, and is more flexible in speed control than the four-cycle type. It is not so steady as the latter, hence not so satisfactory for a refinery primal power unit. On account of fire risks magneto ignition is also desirable.

The essential difference between the operation and construction of the Diesel type of oil engine and that of a standard gas engine is that in the former, the fuel charge must be atomized and compressed to so high a degree that self-ignition (aided by a hot surface in the semi-Diesel type) is obtained. Such a system of ignition obviously requires exceptionally heavy construction, involving high initial cost. The full Diesel type compresses at 550 pounds and injects air at 1000 pounds; the semi-Diesel requires 275 and 600 pounds per square inch respectively. While extremely low-grade fuels have been successfully used in the full Diesel engine, the semi-Diesel modification, operating on crude, fuel oil, or gas oil, is recommended for general refinery practice. Lack of space prevents further description of this class of prime movers, the reader being referred to the various published works [1] on the subject. The appended data

[1] For further information concerning primal power producers consult Marks' Mechanical Engineers' Handbook; Kent's Mechanical Engineers' Pocketbook; Heck, The Steam Engine and Turbine; Clerk, The Gas, Petrol, and Oil Engine; Schöttler, Die Gasmaschine. See "Internal Combustion Engines" in this volume.

shows economies which may be reasonably expected from the various classes of power producers under ordinary service conditions of 75 to 100 per cent load factor. Operating costs may be readily computed by applying local fuel values, and giving due consideration to the investment charge, the manufacturers' guarantees, etc. In this connection it should be noted that a steam engine is sold on its indicated horse-power which may be from 10 to 15 per cent over the actual brake horse-power developed, and that a steam turbine is guaranteed on its water rate; i.e., the number of pounds of steam per hour per shaft horse-power delivered, and if direct-connected to a generator the pounds of steam per hour per kilowatt of output at the terminals of the latter. Oil and gas engines are usually sold on brake horse-power. In addition to guarantees, etc., the potential value of the exhausts from all classes of apparatus listed should be carefully considered when deciding as to ultimate general plant efficiency.

In the tabulation on page 296, the following constants were used as representing average values encountered in routine practice. Where these differ essentially from actual conditions the values in the tables should be modified accordingly. The quantities underscored are for thermal comparison only. They assume that equal efficiencies would have been obtainable had their use been possible.

1 pound coal	=13,000 B.t.u.
1 pound fuel oil	=18,500 B.t.u.
1 pound crude oil	=19,000 B. t.u.
1 cubic foot natural gas =	900 B.t.u.
Evaporation	=8.8 pounds water per pound of coal fired.
Boiler efficiency	=80 per cent.

Generators.—For small plants with a minimum power demand where principally a lighting load is carried, the D.C. type of generator may be installed, but for refineries of moderate or large size, where the current must be carried a considerable distance, only an A.C. unit should be considered. Where it is at all possible that a part of the current required may be purchased from an outside source, the system installed should be synchronous with the prevailing power; in general, however, a 60-cycle three-phase system is best suited for standard needs. Except for small plants a 440-volt system of distribution is recommended, as being convenient, safe, and saving of copper. Somewhat higher voltages are installed in larger plants, but their use is not generally advised.

Motors.—Motors are divided into two general classes, namely direct current (D.C.), and alternating current (A.C.) motors; they are rated either for continuous or intermittent service, and are classified as open, semi-enclosed, and entirely enclosed. For refinery service the continuous open type of motor gives the greatest satisfaction, although the enclosed form may occasionally be installed to advantage in an earth-retort building, or some other point of severe service.

Direct-current motors are divided into three classes, distinguished by the method of connecting the field and armature winding together; namely, series, shunt, and compound. The series motor has its field winding connected in series with its armature winding. In this type of motor, the speed varies automatically with the load, increasing as the load decreases. Where D.C. current is used in complete refinery plants, series motors are used for operating press pumps, ram pumps, rotary fuller's-earth kilns, etc., where heavy demand of power is necessary to bring the machines up to speed, as the series winding takes care of this acceleration with a normal demand of energy. This type of motor should never be installed where it is possible to start under no load, on account of the danger of racing. The shunt motor has its field winding connected in parallel with its armature winding, speed being constant regardless of load. This

Comparison of Average Power Economies of Primal Power Producers

Type unit	Fuel Consumed per Brake Horse-power (Under boilers)			
	Pounds steam	Pounds coal	Cubic feet gas	Pounds 22°–26°Bé. fuel oil
Small steam pump	220.0	25.00	360.0	17.55
Compound steam pump	110.0	12.50	180.0	8.78
Simple steam engine (plain slide valve)	39.6	4.50	64.8	3.16
Simple steam engine (automatic cut-off valves)	33.0	3.75	54.0	2.63
Compound steam engine (4-valve)	26.4	3.00	43.2	2.10
Steam turbine (350 H.P.)	28.2 (W.R.)	3.21	46.2	2.25
Steam turbine (1500 H.P.)	23.2 (W.R.)	2.64	38.0	1.85
	Fuel Consumed per K.W. Delivered Generator Terminals (Under boilers)			
Compound steam engine driving 250 K.W. alternator:				
Turbo-alternator (250 K.W.)	40.0 (W.R.)	4.54	65.4	3.18
Turbo-alternator (1000 K.W.)	33.0 (W.R.)	3.75	54.0	2.63
	Fuel Consumed per Brake Horse-power (Internal-combustion engines)			
Gas engine (150 H.P.)	......	1.38	20.0	0.97
Gas engine (1500 H.P.)	......	0.83	12.0	0.58
Oil engine (125 H.P.)[1]	......	0.68	9.8	0.48
Oil engine (200 H.P.)	......	0.70	10.2	0.50
	Fuel Consumed per K.W. Delivered Generator Terminals (Internal-combustion engines)			
Gas engine driving 250 K.W. alternator	17.7 (W.R.)	......	29.1	......
Oil engine driving 250 K.W. alternator	8.5 (W.R.)	......	......	0.68

[1] Operating on 37.3 gravity crude oil.

motor is most generally used in D.C. wired plants, particularly where group drives are installed, with individual units belt-driven from a line shaft, or operated by clutch control from a line or jack shaft. The compound motor has two distinct field windings, one in series and one in parallel, and is only used for special installations. Commutating-pole motors are sometimes used in D.C. practice to effect a sparkless condition of the commutator, but they should not be depended upon as being absolutely safe operating units in an atmosphere containing explosive gases.

Alternating-current motors are also divided into three classes, induction, synchronous and commutating pole. The induction motor is similar in its performance to a D.C shunt motor, being essentially a constant-speed machine. The wound-rotor type of induction motor is provided with slip-rings so that external resistance may be inserted in the motor circuit, thus effecting greater torque with the slower speed produced when resistance is inserted. Such motors are preferably installed in refinery practice in situations similar to those in which a D.C. series motor would be required. For ordinary refinery service conditions, the squirrel-cage or standard induction motor leaves little to be desired. It is sparkless in running, is rugged in construction, and operates at constant speed within wide variations of load. At starting it requires an excessive current, especially if it must start under full load, so that particularly large-sized motors should have provision for starting light (clutch or by-pass). The synchronous motor is not adapted for refinery use, nor does the alternating-current commutating motor offer any special advantages over the two types of induction motors discussed, as far as refinery service is concerned.

Compressors.—Compressed air is used both in refinery operation and in construction. It is used in the former instance as low-pressure forced draft for burning fine coal and for general air circulating purposes, under slight compression for agitation of oils during treating, and finally as 100 to 125-pound compressed air for handling acid, blowing asphaltum, and furnishing power for pneumatic tools. During construction large quantities of compressed air are used for the last-named purpose, one or more single-stage power-driven compressors taking care of such requirements. For acid agitation a low-pressure type, preferably double-acting power-driven, is advocated, although many of the smaller plants have steam-driven low-stage compressors, or blowers, as they are usually called. Forced draft is generally obtained by the simple fan type of blower, which is also used to circulate air in sweating ovens, etc. Where excessively large volumes are required under a more positive pressure than a fan can produce, the interlocking vane type of blower should be considered. This machine, of which the Roots Company make may be considered typical, is also successfully used in the operation of large plants as an exhauster, where waste still gases must be steadily removed and delivered at a uniform rate. In determining the flow of a given quantity of air through small apertures to effect agitation or dehydration, and in generally estimating the size of compressors needed for plant requirements, the following tables will be of value:

Table Showing the Relative Volumes of Compressed Air at Various Pressures

Gage pressure, pounds	Volume of free air corresponding to 1 cubic foot of air at given pressure	Corresponding volume of 1 cubic foot of free air at given pressure	Gage pressure, pounds	Volume of free air corresponding to 1 cubic foot of air at given pressure	Corresponding volume of 1 cubic foot of free air at given pressure
0	1.00	1.00	70	5.762	0.1735
1	1.068	0.9356	75	6.102	.1638
2	1.136	.8802	80	6.442	.1552
3	1.204	.8305	85	6.782	.1474
4	1.273	.7861	90	7.122	.1404
5	1.34	.7462	95	7.462	.1340
10	1.68	.5951	100	7.802	.1281
15	2.02	.4949	110	8.483	.1178
20	2.36	.4236	120	9.170	.1090
25	2.7	.3703	130	9.843	.1016
30	3.04	.3288	140	10.52	.0950
35	3.38	.2957	150	11.20	.0892
40	3.72	.2687	160	11.88	.0841
45	4.06	.2462	170	12.56	.0796
50	4.40	.2272	180	13.24	.0755
55	4.74	.2109	190	13.92	.0712
60	5.08	.1967	200	14.60	.0684
65	5.42	.1844			

Mechanical transmission of power.—Mechanical power, produced directly or indirectly through the agency of any of the primal sources mentioned in the preceding paragraphs, is transmitted either by direct connection of the drive shaft (often through an intermediary friction or cut-off clutch), by a system of gearing or a series of pulleys and belts, or by sprockets and chains. A detached line or isolated water pump may often be advantageously direct-connected (with intermediary clutch) to an oil- or gas-engine power unit, but in general, where motor drives predominate (modern practice), only centrifugal pumps may be directly joined to the rotor shaft. Triplex pumps are best gear-driven, using cloth or raw-hide pinions, silent chain drives being an equally efficient and noiseless method of power transmission. Belt-driven pulleys operated from a line shaft are still employed where a low initial installation cost must be maintained, and still survive to a great extent in machine shop practice. Link belt or chain is used where strength and freedom from slipping are required, rather than speed, as in a wax chipper or helicoid screw drive. Regarding the power capable of being transmitted through the forms of equipment mentioned, the reader is referred to the manufacturers' guarantees for friction and cut-off clutches, spur and bevel gears, silent chain, link belt, etc. These items naturally differ with the design employed. Several belting formulae also exist, depending on various assumptions of friction coefficient, tractive pull, etc. Those selected in the tables (pages 301-302) are considered good practice for all ordinary conditions. Other transmission formulae of a general nature are included in the list, and, being self-explanatory need no further comment.

Volume of Air (Cubic Feet of Free Air per Minute) that will Flow through Round Holes in a Receiver into the Atmosphere

Diameter of orifice, inches	Gage Pressures in Receiver, Pounds								
	2	5	10	15	20	25	30	35	40
1/64	.038	.0597	.0842	.103	.119	.133	.156	.173	.19
1/32	.153	.242	.342	.418	.485	.54	.632	.71	.77
3/64	.342	.545	.77	.94	1.07	1.21	1.4	1.56	1.71
1/16	.647	.965	1.36	1.67	1.93	2.16	2.52	2.80	3.07
3/32	1.37	2.18	3.06	3.75	4.28	4.84	5.6	6.24	6.84
1/8	2.435	3.86	5.45	6.65	7.7	8.6	10	11.2	12.27
3/16	5.45	8.72	12.3	15	17.1	19.4	22.4	25	27.4
1/4	9.74	15.4	21.8	26.7	30.8	34.5	40	44.7	49.09
3/8	21.95	34.6	49	60	69	77	90	100	110.5
1/2	39	61.6	87	107	123	138	161	179	196.4
5/8	61	96.5	136	167	193	216	252	280	306.8
3/4	87.6	133	196	240	277	310	362	400	442
7/8	119.5	189	267	326	378	422	493	550	601
1	156	247	350	427	494	550	645	715	786
1 1/8	196	310	440	538	620	692	812	900	987
1 1/4	242	384	543	665	770	860	1000	1120	1230
1 3/8	291	464	660	803	929	1040	1200	1350	1480
1 1/2	350	550	780	960	1102	1240	1435	1600	1770
1 3/4	473	752	1068	1304	1505	1680	1960		
2	625	985	1395	1700	1967	2200	2586		

Diameter of orifice, inches	Gage Pressures in Receiver, Pounds									
	45	50	60	70	80	90	100	125	150	200
1/64	.208	.225	.26	.295	.33	.364	.40	.486	.57	.76
1/32	.843	.914	1.05	1.19	1.33	1.47	1.61	1.97	2.33	3.07
3/64	1.91	2.05	2.35	2.68	2.97	3.28	3.66	4.12	5.20	6.9
1/16	3.36	3.64	4.2	4.76	5.32	5.87	6.45	7.85	9.20	12.2
3/32	7.6	8.2	9.4	10.7	11.88	13.1	14.5	17.5	20.8	27.5
1/8	13.4	14.5	16.8	19	21.2	23.5	25.8	31.4	36.7	48.7
3/16	30.4	32.8	37.5	42.9	47.5	52.4	58	70	83.2	110
1/4	53.8	58.2	67	76	85	94	103.2	125.5	147	195.8
3/8	121	130	151	171	191	211	231	282	330	440
1/2	215	232	268	304	340	376	412	502	588	782
5/8	336	364	420	476	532	587	645	785	920	1220
3/4	482	521	604	685	765	843	925	1127	1322	1760
7/8	658	710	622	930	1004	1145	1260	1161	1804	
1	860	930	1070	1215	1360	1500	1648	2000	2350	
1 1/8	1082	1170	1350	1530	1710	1890				
1 1/4	1345	1455	1680	1900	2130	2350				
1 3/8	1630	1760								
1 1/2	1930	2085								
1 3/4										
2										

Theoretical Volume of Equivalent Free Air in Cubic Feet that will Flow per Minute at Various Pressures through Straight Pipes of Different Diameters, Each 100 Feet Long without any Reduction of Pressure

Initial and terminal gage pressure, pounds	Nominal Diameters of Pipes in Inches						
	1	1½	2	2½	3	3½	4
10	24.05	75.67	153.0	244.7	433.3	636.4	883.8
20	28.48	89.54	177.9	288.8	512.9	753.0	1045.0
30	32.35	110.6	202.0	329.1	582.5	855.0	1187.0
40	35.82	112.5	223.5	364.2	644.7	946.4	1314.0
50	38.96	122.4	243.4	396.3	701.5	1030.0	1430.0
60	41.83	131.4	261.1	425.4	752.9	1105.0	1535.0
70	44.53	139.9	278.0	452.9	801.8	1176.0	1634.0
80	47.08	147.9	294.0	478.8	847.6	1244.0	1728.0
90	49.54	155.6	309.3	503.8	891.8	1307.0	1817.0
100	51.88	163.0	324.0	527.5	933.8	1370.0	1904.0
110	54.10	169.9	337.8	550.1	973.9	1429.0	1985.0
125	57.15	179.5	356.8	581.3	1028.0	1510.0	2097.0
150	62.10	195.1	387.8	631.7	1117.0	1641.0	2280.0
175	66.71	209.6	416.5	678.4	1201.0	1762.0	2448.0
200	70.93	222.9	443.0	721.4	1277.0	1874.0	2603.0
250	78.70	247.3	491.4	800.4	1416.0	2079.0	2889.0
300	85.85	269.9	536.3	873.4	1546.0;	2269.0	3152.0
400	98.55	309.9	615.7	1002.0	1775.0	2606.0	3619.0

Initial and terminal gage pressure, pounds	Nominal Diameters of Pipes in Inches							
	5	6	7	8	10	12	15	18
10	1585	2,542	3,701	5,134	9,212	14,530	22,530	36,280
20	1871	3,006	4,381	6,076	10,900	17,210	26,640	42,940
30	2124	3,415	4,975	6,900	12,380	19,540	30,270	48,750
40	2352	3,779	5,507	7,635	13,700	21,620	33,500	53,960
50	2558	4,114	5,993	8,312	14,910	23,520	36,450	58,730
60	2747	4,416	6,433	8,920	16,000	25,260	39,120	63,040
70	2925	4,701	6,848	9,499	17,030	26,900	41,660	67,110
80	3091	4,971	7,240	10,040	18,000	28,430	44,050	70,960
90	3253	5,230	7,619	10,560	18,940	29,920	46,340	74,660
100	3407	5,477	7,979	11,050	19,850	31,330	48,530	78,190
110	3552	5,712	8,320	11,530	20,690	32,670	50,610	81,540
125	3754	6,034	8,789	12,180	21,860	34,520	53,470	86,140
150	4080	6,558	9,553	13,240	23,760	37,520	58,120	93,610
175	4382	7,044	10,250	14,220	25,520	40,300	62,420	100,520
200	4659	7,489	10,900	15,120	27,140	42,850	66,370	106,900
250	5170	8,309	12,100	16,780	30,110	47,550	73,640	118,620
300	5642	9,063	13,210	18,320	32,870	51,800	80,380	
400	6477	10,400	15,160	21,020	37,730	59,580	92,270	

Mean Effective Pressures, Horse-powers and Temperatures for Single and Compound Air Compression Up to 400 Pounds per Square Inch

Single-stage Compression			Gage pressure, pounds	Two-stage or Compound Compression		
Temperature at end of compression (atmosphere 60° F.)	*Horse-power required to compress 100 cubic feet free air per minute	*Mean effective pressure per square inch in cylinder (theoretical)		*Mean effective pressure in terms of low pressure cylinder	*Horse-power required to compress 100 cubic feet free air per minute	Temperature at end of compression (atmosphere 60° F.)
145	3.61	8.3	10			
178	5.04	11.52	15			
207	6.29	14.5	20			
234	7.45	17.03	25			
252	8.48	19.5	30			
281	9.45	21.64	35			
302	10.35	23.68	40			
321	11.18	25.6	45			
339	12.00	27.4	50			
357	12.7	29.14	55			
375	13.42	30.76	60			
389	14.08	31.7	65			
405	14.75	33.75	70	29.38	12.83	214
420	15.35	35.24	75	30.5	13.33	219
432	15.96	36.65	80	31.6	13.80	224
447	16.55	37.96	85	32.6	14.24	229
459	17.07	39.2	90	33.75	14.7	234
472	17.65	40.5	95	34.35	15	239
485	18.18	41.65	100	35.38	15.45	243
507	19.22	43.92	110	37.1	16.2	250
529	20.25	46.06	120	38.8	16.85	257
550	21.2	48.2	130	40	17.5	265
570	21.82	50.05	140	41.98	18.35	272
589	22.64	51.9	150	43.96	19.2	279
607	23.42	53.66	160	44.6	19.5	285
624	24.24	55.4	170	45.32	19.8	291
640	24.93	57.03	180	46.6	20.34	297
657	25.64	58.6	190	47.5	20.77	303
672	26.25	60.16	200	48.54	21.2	309
715	27.78	63.6	225	50.5	22	320
749	29.2	66.82	250	52.45	22.88	331
780	30.57	70	275	54.4	23.72	342
815	31.68	72.5	300	56.35	24.56	352
837	32.76	75	325	58.1	25.36	361
867	34.18	78.2	350	59.88	26.17	370
892	35.37	80.94	375	61.7	26.95	375
915	36.25	83.25	400	63.55	27.75	380

* An addition of 15 per cent should be made for friction and in-take temperatures higher than 60° F. on which this table is based. Atmospheric pressure assumed at 14.7 pounds per square inch. No account taken of jacket cooling.

To find the capacity of an air compressor in cubic feet of free air per minute: Multiply the area of low-pressure cylinder (on compound compressor), or area of simple compressor cylinder in square inches, by the stroke in inches, and divide by 1728; and multiply this result:

(*a*) In single-acting, simple or compound, by the R.P.M.
(*b*) Double-acting, simple or compound, by 2×R.P.M.
(*c*) Duplex double-acting, by 4×R.P.M.

Horse-power Transmitted by Steel Shafting

As prime mover or head shaft well supported by bearings

Formula: $$H.P. = \frac{D^3R}{100}$$

where D = diameter in inches,

R = R.P.M.

	R.P.M.											
D	100	125	150	175	200	250	300	350	400	450	500	550
1	1	1.2	1.5	1.7	2	2.5	3	3.5	4	4.5	5	5.5
$1\frac{1}{2}$	3.4	4.2	5	5.9	6.7	8.4	10.1	11.8	13.5	15.2	16.9	18.5
$1\frac{11}{16}$	4.8	6	7.2	8.4	9.6	12	14.4	16.8	19.2	22	24	26
$1\frac{15}{16}$	7.3	9	10.9	12.7	14.5	18.2	22	25	29	33	36	40
2	8	10	12	14	16	20	24	28	32	36	40	44
$2\frac{3}{16}$	10.5	13	15.7	18.4	21	26	31	37	42	47	52	58
$2\frac{7}{16}$	14.5	18	22	25	29	36	43	51	58	65	72	79
$2\frac{11}{16}$	19.4	24	29	34	39	48	58	68	77	87	97	107
$2\frac{15}{16}$	25	32	38	44	51	63	76	89	101	114	127	139
3	27	34	40	47	54	67	81	94	108	122	135	148
$3\frac{3}{16}$	32	40	48	56	65	81	97	113	129	145	162	178
$3\frac{7}{16}$	41	50	61	71	81	101	122	142	162	183	203	223
$3\frac{11}{16}$	50	63	75	88	100	125	150	176	200	226	251	276
$3\frac{15}{16}$	61	76	91	107	122	152	183	213	244	275	305	335
$4\frac{3}{16}$	74	92	110	128	147	184	221	251	294	331	367	404
$4\frac{7}{16}$	88	109	132	153	175	219	263	307	350	395	438	482
$4\frac{15}{16}$	120	151	182	212	241	302	364	424	485	545	604	667
6	216	270	323	378	431	540	648	755	863	971	1080	1190
7	343	428	515	600	859	1030	1200					

As second movers or line shafts, bearings 8 feet apart

Formula: $$H.P. = \frac{D^3R}{70}$$

where D = diameter in inches,

R = R.P.M.

	R.P.M.											
D	100	125	150	175	200	250	300	350	400	450	500	550
1	1.4	1.8	2.1	2.5	2.8	3.6	4.3	5	5.7	6.4	7.1	7.8
$1\frac{1}{2}$	4.8	6	7.2	8.4	9.6	12	14.4	16.9	19.2	22	24	26
$1\frac{11}{16}$	6.9	8.6	10.3	12	13.7	17.1	21	24	27	31	34	38
$1\frac{15}{16}$	10.4	13	15.6	18.2	21	26	31	36	42	47	52	57
2	11.4	14.3	17.2	20	23	29	34	40	46	51	57	63
$2\frac{3}{16}$	15	18.7	22	26	30	37	45	52	60	67	75	82
$2\frac{7}{16}$	20	25	30	33	41	51	61	72	81	91	102	112
$2\frac{11}{16}$	28	35	42	48	55	69	83	97	111	124	133	152
$2\frac{15}{16}$	36	45	54	63	72	90	108	127	144	162	181	199
3	39	48	58	67	77	96	116	135	154	173	192	212
$3\frac{3}{16}$	46	58	69	81	92	115	139	162	185	208	231	253
$3\frac{7}{16}$	58	73	87	101	116	145	174	203	232	261	290	319
$3\frac{11}{16}$	72	89	107	125	143	179	215	251	286	322	358	393
$3\frac{15}{16}$	87	109	131	152	174	218	251	305	349	392	436	480

The following rules are given for determining pulley diameters:

$$\text{Diameter of driver} = \frac{\text{diameter of driven} \times \text{number of revolutions}}{\text{number of revolutions of driver}}.$$

$$\text{Diameter of driven} = \frac{\text{diameter of driver} \times \text{number of revolutions}}{\text{number of revolutions of driven}}.$$

$$\text{Revolutions of driven} = \frac{\text{diameter of driver} \times \text{number of revolutions}}{\text{diameter of driven}}.$$

$$\text{Revolutions of driver} = \frac{\text{diameter of driven} \times \text{number of revolutions}}{\text{diameter of driver}}.$$

Belting Practice

Let d = diameter of pulley in inches; πd = circumference;
V = velocity of belt in feet per second; v = velocity in feet per minute;
a = angle of the arc of contact;
L = length of arc of contact in feet $= \pi da \div (12 \times 360)$;
F = tractive force per square inch of sectional area of belt;
w = width in inches; t = thickness;
S = tractive force per inch of width $= F \times t$;
R.P.M. = revs. per minute; R.P.S. = revs. per second = R.P.M. ÷ 60;

$$V = \frac{\pi d}{12} \times \text{R.P.S.} = \frac{\pi d}{12} \times \frac{\text{R.P.M.}}{60} = 0.004363 d \times \text{R.P.M.} = \frac{d \times \text{R.P.M.}}{229.2};$$

$$v = \frac{\pi d}{12} \times \text{R.P.M.} = 0.2618 d \times \text{R.P.M.}$$

$$\text{Horse-power, H.P.} = \frac{Svw}{33000} = \frac{SVw}{550} = \frac{Swd \times \text{R.P.M.}}{126050}.$$

Many writers give as safe practice for single belts in good condition a working tension of 45 pounds per inch of width. This gives

$$\text{H.P.} = \frac{wv}{733} = 0.0818\,Vw = 0.000357 wd \times \text{R.P.M.} = \frac{wd \times \text{R.P.M.}}{2800}. \quad . \quad . \quad . \quad (1)$$

For double belts of average thickness, some writers say that the transmitting efficiency is to that of single belts as 10 to 7, which would give

$$\text{H.P.} = \frac{wc}{513} = 0.1169\,Vw = 0.00051 wd \times \text{R.P.M.} = \frac{wd \times \text{R.P.M.}}{1960}. \quad . \quad . \quad . \quad (2)$$

Other authorities, however, make the transmitting power of double belts twice that of single belts, on the assumption that the thickness of a double belt is twice that of a single belt.

Rules for horse-power of belts are sometimes based on the number of square feet of surface of the belt which pass over the pulley in a minute. Square feet per minute = $wv \div 12$. The above formulae translated into this form give:

(1) For S = 45 pounds per inch wide; H.P. = 61 sq. ft. per minute.

(2) For S = 64.3 pounds per inch wide; H.P. = 43 sq. ft. per minute (double belt).

The above formulae are all based on the supposition that the arc of contact is 180°. For other arcs, the transmitting power is approximately proportional to the ratio of the degrees of arc to 180°.

Some rules base the horse-power on the length of the arc of contact in feet.

$$\text{Since} \quad L=\frac{\pi da}{12\times 360} \quad \text{and} \quad \text{H.P.}=\frac{Svw}{33000}=\frac{Sw}{33000}\times\frac{\pi d}{12}\times\text{R.P.M.}\times\frac{a}{180}$$

we obtain by substitution $\text{H.P.}=\frac{Sw}{16500}\times L\times\text{R.P.M.}$, and the five formulas then take the following form for the several values of S:

$$\text{H.P.}=\frac{wL\times\text{R.P.M.}}{367} \ (1); \qquad \text{H.P. (double belt)}=\frac{wL\times\text{R.P.M.}}{257} \ (2).$$

Horse-power of a Belt 1 Inch Wide, Arc of Contact 180°

Comparison of different formulae

Velocity in feet per second	Velocity in feet per minute	Square feet of belt per minute	Form 4, $\text{H.P.}=\frac{wv}{733}$	Form 5, double belt, $\text{H.P.}=\frac{wv}{513}$
10	600	50	0.82	1.17
20	1200	100	1.64	2.34
30	1800	150	2.46	3.51
40	2400	200	3.27	4.68
50	3000	250	4.09	5.85
60	3600	300	4.91	7.02
70	4200	350	5.73	8.19
80	4800	400	6.55	9.36
90	5400	450	7.37	10.53
100	6000	500	8.18	11.70

In the above table the angle of subtension, a, is taken at 180°.

Should it be......	90°	100°	110°	120°	130°	140°	150°	160°	170°	180°	200°
Multiply above values by.......	0.65	0.70	0.75	0.79	0.83	0.87	0.91	0.94	0.97	1	1.05

Width of belt for a given horse-power.—The width of belt required for any given horse-power may be obtained by transposing the formulae for horse-power so as to give the value of w. Thus:

$$\text{From formula (1),} \quad w=\frac{733\text{ H.P.}}{v}=\frac{12.22\text{ H.P.}}{V}=\frac{2800\text{ H.P.}}{d\times\text{R.P.M.}}=\frac{360\text{ H.P.}}{L\times\text{R.P.M.}}.$$

$$\text{From formula (2),} \quad w=\frac{513\text{ H.P.}}{v}=\frac{8.56\text{ H.P.}}{V}=\frac{1960\text{ H.P.}}{d\times\text{R.P.M.}}=\frac{257\text{ H.P.}}{L\times\text{R.P.M.}}.$$

Good oak-tanned leather from the back of the hide weighs almost exactly one avoirdupois ounce for each one-hundredth of an inch in thickness, in a piece of leather one foot square, so that

	Weight per square foot, ounces	Approximate inches	Actual thickness, inches	Velocity per inch for 1 H.P.,	Safe strain per inch, width, pounds
Single belt.	16	$\frac{1}{6}$	0.16	625	52.8
Light double.	24	$\frac{1}{4}$	0.24	417	78.1
Medium.	28	$\frac{5}{16}$	0.28	357	92.5
Standard.	33	$\frac{1}{3}$	0.33	303	109
3-ply.	45	$\frac{9}{16}$	0.45	222	148

The rule for velocity per inch width for 1 H.P. is:

Multiply the denominator of the fraction expressing the thickness of the belt in inches by 100, and divide it by the numerator;

Good, well-calendered rubber belting made with 30-ounce duck and new (i.e., not reclaimed vulcanized) rubber will be as follows:

Nomenclature	Approximate thickness, inch	Safe working strain for 1 inch width, pounds	Velocity per inch for 1 horse-power, feet per minute
3-ply.	0.18	45	735
4-ply.	0.24	65	508
5-ply.	0.30	85	388
6-ply.	0.35	105	314
7-ply.	0.40	125	264
8-ply.	0.45	145	218

The thickness of the rubber belt does not necessarily govern the strength, but the weight of duck does, and with 30-ounce duck, the safe working strains are as above.

Horse-power required by belt conveyors.—The following formula will give approximately the horse-power required to drive belt conveyors

$$\text{H.P.} = \frac{C \times T \times L}{1000} + \frac{T \times H}{1000},$$

where C = power constant from table below;
T = load in tons per hour;
L = length of conveyor between centers, in feet;
H = vertical height in feet that material is to be lifted.

Add for each movable or fixed tripper the horse-power in column 4.

Add 50 per cent to horse-power for each conveyor under 50 feet in length.

Add 25 per cent to horse-power for each conveyor between 50 feet and 100 feet in length.

Width of belt, inches	"C" for material weighing 25 pounds to 75 pounds per cubic foot	"C" for material weighing 75 pounds to 125 pounds per cubic foot	H.P. for each movable or fixed tripper	Width of belt, inches	"C" for material weighing 25 pounds to 75 pounds per cubic foot	"C" for material weighing 75 pounds to 125 pounds per cubic foot	H.P. for each movable or fixed tripper
12	0.235	0.15	½	26	0.19	0.13	2
14	0.230	0.15	½	28	0.18	0.12	2¼
16	0.220	0.14	¾	30	0.17	0.12	2½
18	0.21	0.14	1	32	0.17	0.12	2¾
20	0.21	0.14	1¼	34	0.16	0.12	3
22	0.2	0.13	1½	36	0.16	0.12	3¼
24	0.2	0.13	1¾				

In figuring the horse-power of belt conveyors always figure the maximum capacity of conveyor at the speed selected.

Thickness of belt.—The stress in the belt may be determined, after the horse-power has been figured, by the following formula:

$$X = \frac{\text{H.P.} \times 33{,}000}{S \times B},$$

where X = stress in belt, in pounds per inch of width;
S = belt speed in feet per minute;
B = width of belt in inches.

The stress per inch of width for one ply should never exceed 20 pounds. Dividing the value X obtained above by 20 will give the number of plies necessary for strength.

Link belting.—For chains used as drive chains, it is recommended that the working load shall not exceed the following:

Speed of chain, feet per minute	Divide average ultimate strength by the following factor
200 feet and under.......	6
200 to 300..............	8
300 to 400..............	10
400 to 500..............	12
500 to 600..............	16
600 to 700..............	20

Capacities of Helicoid Conveyors

Size of helicoid conveyor, inches	3	4	5	6	7	8	9	10	12	14	16
Speed R.P.M.	125	125	120	115	110	105	100	95	90	85	80
Cubic feet per hour	20	43	95	126	178	359	421	540	933	1200	2000

Coal Screenings, or Small-sized Coal, with No Lumps Larger than 1 Inch

*Size of helicoid conveyor, inches	7	8	9	10	12	14	16
Speed, R.P.M.	110	105	100	95	90	85	80
Cubic feet per hour	269	544	650	838	1460	1905	3260
Tons (2000 pounds) per hour	6.7	13.6	16.3	20.9	36.5	47.5	79.0

* Small sizes of helicoid conveyor are not recommended for handling coal.

Horse-power required by helicoid conveyors.—H.P. $= \dfrac{K \times C \times W \times L}{2{,}000{,}000}$,

where $K = 2.5$ for fine coal, etc.;
$= 4.0$ for sand, ashes, fuller's earth, etc.;
C = capacity in cubic feet per hour;
W = weight of material per cubic foot;
L = length of conveyor in feet.

It is to be understood that with screw conveyors a great deal depends upon the specific nature and condition of the material to be handled, and for this reason no formula is entirely satisfactory in all cases.

Metering, measuring, and control devices.—Oil, gas, water, and steam meters are extensively used in refinery operations, as checks on deliveries, process movements, and fuel economies. Piston-type, rotating-disk, V-notch orifice, and jet-meters are all employed. Temperature measurements up to 800° F. are effected preferably by a mercurial or ether-filled indicating or recording thermometer, and higher furnace temperatures by a thermoelectrical instrument. Various automatic controls, such as the Foster, for feed-water supply, the Fulton, for regulating gas pressure, and the Tagliabue, for temperature control all fill an important place, but lack of space makes it necessary to omit the description of these and other apparatus of similar purpose. The reader is referred to the various trade catalogues and current technical magazines for details of construction and manner of operation.

Chimneys.—While many refineries are built with separate steel stacks for each boiler, still, etc., chimneys of brick or cement should be installed for permanent construction. Reinforced cement stacks with a liner for one-half of the height have been quite generally adopted, especially for boilers in batteries. The strength of materials employed allows a lighter weight and permits much cheaper construction than the corresponding brick stack. The height for such a stack for standard boiler practice is shown in the appended table. Heights of more than 150 feet are, however, not justified by the increased efficiency obtained, and are rarely constructed at present. Two or more chimneys are built if one of 150 feet is not sufficient.

Size of Chimneys for Steam Boilers

Formula, H.P. $= 3.33(A - 0.6\sqrt{A})\sqrt{H}$. (Assuming 1 H.P. = 5 pounds of coal burned per hour)

Diameter, inches	Area A, square feet	Effective area, $E = A - 0.6\sqrt{A}$, square feet	Height of Chimney in Feet														Equivalent square chimney. Side of square, $\sqrt{E}+4$ ins.
			50	60	70	80	90	100	110	125	150	175	200	225	250	300	
			Commercial horse-power of boiler														
18	1.77	0.97	23	25	27	29	....	....	....	....	....	....	....	....	....	....	16
21	2.41	1.47	35	38	41	44	....	....	....	....	....	....	....	....	....	....	19
24	3.14	2.08	49	54	58	62	66	....	....	....	....	....	....	....	....	....	22
27	3.98	2.78	65	72	78	83	88	....	....	....	....	....	....	....	....	....	24
30	4.91	3.58	84	92	100	107	113	119	....	....	....	....	....	....	....	....	27
33	5.94	4.48	....	115	125	133	141	149	156	....	....	....	....	....	....	....	30
36	7.07	5.47	....	141	152	163	173	182	191	204	....	....	....	....	....	....	32
39	8.30	6.57	....	....	183	196	208	219	229	245	268	....	....	....	....	....	35
42	9.62	7.76	....	....	216	231	245	258	271	289	316	342	....	....	....	....	38
48	12.57	10.44	....	....	....	311	330	348	365	389	426	460	492	....	....	....	43
54	15.90	13.51	....	....	....	....	427	449	472	503	551	595	636	675	....	....	48
60	19.64	16.98	....	....	....	....	536	565	593	632	692	748	800	848	894	....	54
66	23.76	20.83	....	....	....	....	....	694	728	776	849	918	981	1040	1097	1201	59
72	28.27	25.08	....	....	....	....	....	835	876	934	1023	1105	1181	1253	1320	1447	64
78	33.18	29.73	....	....	....	....	....	....	1038	1107	1212	1310	1400	1485	1565	1715	70
84	38.48	34.76	....	....	....	....	....	....	1214	1294	1418	1531	1637	1736	1830	2005	75
90	44.18	40.19	....	....	....	....	....	....	....	1496	1639	1770	1893	2008	2116	2318	80
96	50.27	46.01	....	....	....	....	....	....	....	1712	1876	2027	2167	2298	2423	2654	86
102	56.75	52.23	....	....	....	....	....	....	....	1944	2130	2300	2459	2609	2750	3012	91
108	63.62	58.83	....	....	....	....	....	....	....	2090	2399	2592	2771	2939	3098	3393	96
114	70.88	65.83	....	....	....	....	....	....	....	....	2685	2900	3100	3288	3466	3797	101
120	78.54	73.22	....	....	....	....	....	....	....	....	2986	3226	3448	3657	3855	4223	107
132	95.03	89.18	....	....	....	....	....	....	....	....	3637	3929	4200	4455	4696	5144	117
144	113.10	106.72	....	....	....	....	....	....	....	....	4352	4701	5026	5331	5618	6155	128

For pounds of coal burned per hour for any given size of chimney, multiply the figures in the table by 5.

Where oil is used for fuel, the sizes of chimneys may be considerably reduced, as determined by Weymouth,[1] and given below.

Chimney table for oil fuel.—Conditions: Sea level; atmospheric temperature, 80° F.; draught at chimney side of damper, 0.30 inch; excess air, less than 50 per cent, assumed 50 per cent for calculations of efficiency and chimney dimensions; temperature of gases leaving chimney, 500° F.; boiler efficiency, 73 per cent; actual boiler horse-power, 150 per cent of rated; pounds of gas per actual boiler H.P., 54.6; height of chimney above point of draught measurement, 12 feet less than tabulated height. When building conditions permit select chimneys of least height in table for minimum cost of chimney. Chimney capacities stated are maximum for continuous load equally divided on all boilers. For large plants or swinging load, reduce capacity 10 to 20 per cent. Breeching 20 per cent in excess of stack area; length not exceeding 10 chimney diameters.

Size of Chimneys for Oil Fuel

Diameter, inches	Area, square feet	Height in Feet above Boiler-room Floor								
		80	90	100	110	120	130	140	150	160
		Actual horse-power = 150 per cent of rated								
18	1.77	63	75	84	91	96	101	104	108	110
24	3.14	123	148	166	180	191	201	208	215	221
30	4.91	206	249	280	304	324	340	354	366	377
36	7.07	312	379	427	466	497	523	545	564	581
42	9.62	443	539	609	665	711	749	782	810	830
48	12.57	599	729	827	904	967	1,020	1,070	1,110	1,145
54	15.90	779	951	1,080	1,180	1,270	1,340	1,400	1,460	1,500
60	19.64	985	1,200	1,370	1,500	1,610	1,710	1,790	1,860	1,920
66	23.76	1,220	1,490	1,700	1,860	2,000	2,120	2,220	2,310	2,390
72	28.27	1,470	1,810	2,060	2,260	2,430	2,580	2,710	2,820	2,910
78	33.18	1,750	2,150	2,460	2,710	2,910	3,000	3,250	3,380	3,510
84	38.49	2,060	2,530	2,900	3,190	3,440	3,650	3,840	4,000	4,150
96	50.27	2,750	3,390	3,880	4,290	4,630	4,920	5,180	5,400	5,610
108	63.62	3,550	4,380	5,020	5,550	6,000	6,390	6,730	7,030	7,300
120	78.54	4,440	5,490	6,310	6,990	7,560	8,060	8,490	8,890	9,240
132	95.03	5,450	6,740	7,760	8,600	9,310	9,930	10,500	11,000	11,400
144	113.1	6,550	8,120	9,350	10,400	11,200	12,000	12,700	13,300	13,800
156	132.7	7,760	9,630	11,100	12,300	13,400	14,300	15,100	15,800	16,500
168	153.9	9,060	11,300	13,000	14,400	15,700	16,800	17,700	18,600	19,400
180	176.7	10,500	13,000	15,100	16,700	18,200	19,500	20,600	21,600	22,600

In using the above table it must be noted that the conditions upon which it is based are all fairly good. With unskillful handling of oil fuel the excess air is apt to be much more than 50 per cent and the efficiency much less than 73 per cent. In that case

[1] C. R. Weymouth, Journal A. S. M. E., October, 1912.

the actual horse-power developed by a given size of chimney may be much less than the figure given in the table.

Draught of Chimneys 100 Feet High—Oil Fuel

Temperature of gases entering chimney, degrees F.		300	400	500	600	700
		NET CHIMNEY DRAUGHT, INCHES OF WATER				
Temperature of outside air	60° F.	0.367	0.460	0.534	0.593	0.642
	80° F.	0.325	0.417	0.490	0.550	0.599
	100° F.	0.284	0.377	0.451	0.510	0.559

The net draught is the theoretical draught due to the difference in weight of atmospheric air and chimney gases at the stated temperatures, multiplied by a coefficient, 0.95, for temperature drop in stack, and by $\frac{5}{6}$ as a correction for friction. For high altitudes the draught varies directly as the normal barometer. For other heights than 100 feet (measured above the level of entrance of the gases) the draught varies as the square root of the height.

While concrete stacks are employed for stills in batteries, their use is not especially recommended on account of the ever-prevalent danger of leaking still bottoms with the possibility of a severe fire, resulting in permanent damage to the stack. Separate chimneys for each battery of 10 to 12 stills, constructed of radial brick (fire-brick lined for half their height) are advocated for general refinery practice. The height of chimneys is reduced in accordance with the immediately preceding table if oil or gas is used for fuel, or if forced draught is utilized in burning coal. In the latter case a chimney ceases to function in its original sense, and serves more or less as a means for the conveyance of products of combustion to a point where they will cause no inconvenience. On account of a possible change of fuel base at a later period, it is always a wise plan to provide dampers in initial construction for draft control.

In general, chimneys should be designed to resist the maximum force of the wind in the locality in which they are built. According to Kent,[1] a general rule for the diameter of the base of brick chimneys, approved by many years of practice in England and the United States, is to make the diameter of the base one-tenth of the height. If the chimney is square or rectangular, make the diameter of the inscribed circle of the base one-tenth of the height. The "batter" or taper of a chimney should be from $\frac{1}{16}$ to $\frac{1}{4}$ inch to the foot on each side. The brickwork should be one brick (8 or 9 inches) thick for the first 25 feet from the top, increasing $\frac{1}{2}$ brick (4 or $4\frac{1}{2}$ inches) for each 25 feet from the top downwards. If the inside diameter exceeds 5 feet, the top length should be $1\frac{1}{2}$ bricks; and if under 3 feet, it may be $\frac{1}{2}$ brick for 10 feet.

The stability of the chimney to resist the force of the wind depends mainly on the weight of its outer shell, and the width of its base. The cohesion of the mortar may add considerably to its strength; but it is too uncertain to be relied upon. The inner shell will add a little to the stability, but it may be cracked by the heat, and its beneficial effect, if any, is too uncertain to be taken into account.

[1] Kent's Mechanical Engineers' Pocketbook, p. 954.

The effect of the joint action of the vertical pressure due to the weight of the chimney and the horizontal pressure due to the force of the wind is to shift the center of pressure at the base of the chimney, from the axis toward one side, the extent of the shifting depending on the relative magnitude of the two forces. If the center of pressure is brought too near the side of the chimney, it will crush the brickwork on that side, and the chimney will fall. A line drawn through the center of pressure, perpendicular to the direction of the wind, must leave an area of brickwork between it and the side of the chimney, sufficient to support half the weight of the chimney; the other half of the weight being supported by the brickwork on the windward side of the line.

For chimneys 4 feet in diameter and 100 feet high, and upwards, the best form is circular with a straight batter on the outside.

Chimneys of any considerable height are not built up of uniform thickness from top to bottom, nor with a uniformly varying thickness of wall, but the wall, heaviest, of course, at the base, is reduced by a series of steps.

Where practicable the load on a chimney foundation should not exceed 2 tons per square foot in compact sand, gravel, or loam. Where a solid rock-bottom is available for foundation, the load may be greatly increased. If the rock is sloping, all unsound portions should be removed, and the face dressed to a series of horizontal steps, so that there shall be no tendency to slide after the structure is finished.

All boiler-chimneys of any considerable size should consist of an outer stack of sufficient strength to give stability to the structure, and an inner stack or core independent of the outer one. This core is, by many engineers, extended up to a height of but 50 or 60 feet from the base of the chimney, but the better practice is to run it up the whole height of the chimney; it may be stopped off, say, a couple of feet below the top, and the outer shell contracted to the area of the core, but the better way is to run it up to about 8 or 12 inches of the top and *not* contract the outer shell. But under no circumstances should the core at its upper end be built into or connected with the outer stack. This has been done in several instances by bricklayers, and the result has been the expansion of the inner core which lifted the top of the outer stack squarely up and cracked the brickwork.

For a height of 100 feet the outer shell should be made in three steps, the first 20 feet high, 16 inches thick, the second 30 feet high, 12 inches thick, the third 50 feet high and 8 inches thick. These are the minimum thicknesses admissible for chimneys of this height, and the batter should be not less than 1 in 36 to give stability. The core should also be built in three steps, each of which may be about one-third the height of the chimney, the lowest 12 inches, the middle 8 inches, and the upper step 4 inches thick. This will insure a good sound core. The top of a chimney may be protected by a cast-iron cap; or perhaps a cheaper and equally good plan is to lay the ornamental part in some good cement, and plaster the top with the same material.

Cooling towers and spray ponds.—In many localities, on account of water shortage, it is necessary to recover and cool condensing water, using the same repeatedly. The equipment for attaining this end may be either a cooling tower or a spray pond, the former consisting of an elevated wooden structure of V-troughs or wood baffles so arranged that water fed to top will descend by gravity over a widespread surface, dripping from trough to trough, or baffle to baffle; the object being to afford a large area for exchange of heat from water to air, and facilitate evaporation. The cooling of water in a tower or spray is effected in three ways: first, by the practically negligible effect of radiation; second, by the absorption or conduction of heat by the surrounding air, producing from one-fifth to one-third of the cooling effect; and lastly by evaporation. When evaporation is rapid, water can actually be cooled below the prevailing atmospheric temperature, but any excessive evaporation of course reduces the percentage of recovery and increases the mineral content, an undesirable but often unavoidable feature.

It has already been stated that the evaporation of water requires approximately 1000 heat units, the rapidity of evaporation being determined by the temperature of the water and the vapor tension of the air in immediate contact. Ordinary air is not saturated, and even when saturated air is used, its contact with the warm water of the tower or spray will increase its temperature, at the same time allowing it to absorb additional vapor and thus rendering the cooling cycle more or less independent of climatic conditions. From these facts it is evident that there are two essentials in cooling tower design; first, to present a large surface of water to air; and second, to provide for bringing constantly into contact with this surface the largest possible volume of new air with a minimum expenditure of energy.

The exact quantity of air necessary to effect maximum cooling may be computed from theoretical considerations,[1] and is so computed in scientific cooling-tower design. In spray-pond system, provided sprays are not too closely spaced, the presence of a maximum quantity of air may be considered at all times, giving a pond layout an advantage equal to that of the draught obtained in a tower, especially if the pond site is in a comparatively open location. Another obvious advantage of the spray pond, where spray nozzles are properly designed for service head, is the production of a finer mist than is possible with a gravity-drop tower, affording greater surface contact (heat absorption) and a greater percentage of evaporation (cooling effect).

The accompanying tables [1] show the theoretical volumes of air required for cooling under different temperature conditions based on the formula below and also the amount of water evaporated. The final table (page 315) shows the actual results obtained in practice by the Spraco cooling system, much employed in refinery practice.

Kent gives the following method of calculation of the air supply for cooling tower: Let T_1 and T_2 be the temperatures of the water entering and leaving; t_1 temperature of the air supply; z its relative humidity; t_2, temperature of the air leaving; $m_1 m_2$, pounds of moisture in one pound of saturated air at temperatures t_1, t_2; e_1, e_2, total heat, B.t.u., above 32° F. per pound of water vapor at temperatures t_1, t_2; $A =$ pounds of air supplied per pound of entering water. All temperatures are in degrees F.

Then, for each 1 pound of water entering the tower the heat (B.t.u.) carried in is: by the water, T_1-32; by the air, $0.2375\,A(t_1-32)+Am_1e_1z$. The heat carried out is: by the water, $[1-(m_2-m_1z)]\times(T_2-32)$; by the air, $0.2375\,A(t_2-32)+A(m_2e_2)$. Neglectin loss by radiation, the heat carried into the tower equals the heat leaving it. Equating these quantities and solving for A we have:

$$A=\frac{T_1-T_2+(m_2-m_1z)(T_2-32)}{0.2375(t_2-t_1)+m_2e_2-m_1e_1z}.$$

Values of e_1 or e_2

Temperature, degrees F.	50	70	80	84	88	92
B.t.u.	1081.4	1090.3	1094.8	1096.6	1098.3	1100.1
Temperature, degrees F.	94	98	102	104	108	112
B.t.u.	1101.0	1102.7	1104.5	1105.4	1107.1	1108.9

Water evaporated in a cooling tower.—The following tables give the values of (m_2-m_1z) per pound of air in the cooling-tower formula. Multiplying these values by the number of pounds of air per pound of water for the given conditions, will give the amount of water evaporated, or make-up water required with surface condensers, per pound of the inflowing water.

[1] Kent, Mechanical Engineers' Pocketbook (p. 1080).

Pounds of Air per Pound of Circulating Water

Outflowing air saturated

$T_1 = 100°$		$t_1 = 50°$			70°			80°		
T_2	t_2	$z = 0.5$	0.7	0.9	0.5	0.7	0.9	0.5	0.7	0.9
70	92	0.739	0.767	0.798	0.962	1.044	1.175	1.144	1.382	1.755
	88	0.846	0.884	0.926	1.124	1.278	1.482	1.428	1.831	2.562
	84	0.975	1.026	1.083	1.366	1.604	1.944	1.850	2.598	4.394
80	92	0.508	0.527	0.547	0.644	0.713	0.800	0.783	0.939	1.187
	88	0.580	0.605	0.632	0.767	0.869	1.004	0.971	1.239	1.725
	84	0.665	0.699	0.737	0.927	1.086	1.312	1.253	1.751	2.947
90	92	0.280	0.287	0.297	0.348	0.382	0.424	0.422	0.496	0.619
	88	0.313	0.326	0.338	0.409	0.460	0.527	0.514	0.647	0.888
	84	0.356	0.372	0.390	0.491	0.569	0.680	0.655	0.904	1.500
$T_1 = 110°$		$t_1 = 50°$			70°			90°		
70	102	0.710	0.729	0.750	0.838	0.898	0.966	1.135	1.388	1.790
	98	0.804	0.829	0.856	0.975	1.056	1.155	1.406	1.821	2.596
	94	0.915	0.948	0.983	1.144	1.260	1.403	1.796	2.543	4.395
80	102	0.546	0.561	0.576	0.644	0.688	0.739	0.868	1.055	1.358
	98	0.617	0.636	0.655	0.746	0.807	0.880	1.071	1.382	1.962
	94	0.700	0.724	0.751	0.873	0.960	1.067	1.364	1.898	3.312
90	102	0.383	0.392	0.402	0.449	0.478	0.512	0.600	0.726	0.926
	98	0.430	0.442	0.455	0.517	0.558	0.606	0.736	0.942	1.328
	94	0.484	0.501	0.518	0.602	0.659	0.730	0.931	1.311	2.229
$T_1 = 120°$		$t_1 = 50°$			70°			90°		
70	112	0.651	0.663	0.677	0.732	0.767	0.806	0.894	0.007	1.155
	108	0.733	0.749	0.766	0.839	0.886	0.939	1.061	1.227	1.458
	104	0.828	0.849	0.871	0.967	0.031	1.104	1.278	1.530	1.918
80	112	0.533	0.544	0.554	0.599	0.627	0.656	0.729	0.820	0.938
	108	0.599	0.612	0.625	0.687	0.722	0.764	0.863	0.996	1.180
	104	0.675	0.692	0.710	0.787	0.838	0.896	1.037	1.246	1.548
90	112	0.416	0.423	0.432	0.468	0.487	0.510	0.565	0.633	0.721
	108	0.465	0.475	0.485	0.531	0.558	0.590	0.666	0.765	0.902
	104	0.522	0.535	0.548	0.607	0.645	0.688	0.796	0.947	1.178

Weight of Water Vapor Mixed with 1 Pound of Air at Atmospheric Pressure

Full saturation

Degrees F.	Moisture, pound	Degrees F.	Moisture, pound	Degrees F.	Moisture, pound	Degrees, F.	Moisture, pound	Degrees F.	Moisture, pound
32	0.00374	54	0.00874	76	0.01917	98	0.04002	120	0.08099
34	.00406	56	.00940	78	.02054	100	.04270	122	.08629
36	.00439	58	.01012	80	.02200	102	.04555	124	.09193
38	.00475	60	.01089	82	.02353	104	.04858	126	.09794
40	.00514	62	.01171	84	.02517	106	.05182	128	.10437
42	.00555	64	.01259	86	.02692	108	.05527	130	.11123
44	.00600	66	.01353	88	.02879	110	.05893	132	.11855
46	.00648	68	.01453	90	.03077	112	.06281	134	.12637
48	.00699	70	.01557	92	.03288	114	.06695	136	.13473
50	.00753	72	.01669	94	.03511	116	.07134	138	.14367
52	.00812	74	.01789	96	.03750	118	.07601	140	.15324

Pounds Water Evaporated per Pound of Air

	$t_1 = 50°$			70°			80°		
$T_1 = 100°$	$z = 0.5$	0.7	0.9	0.5	0.7	0.9	0.5	0.7	0.9
$t_2 =$ 92	0.02912	0.02761	0.02610	0.02510	0.02198	0.01887	0.02188	0.01748	0.01308
88	.02503	.02352	.02201	.02101	.01789	.01478	.01779	.01339	.00899
84	.02141	.01990	.01839	.01739	.01427	.01116	.01417	.00977	.00537
$T_1 = 110°$	$t_1 = 50°$			70°			90°		
$t_2 =$ 102	0.01479	0.04028	0.03887	0.03777	0.03465	0.03154	0.03017	0.02402	0.01785
98	.03626	.03475	.03324	.03224	.02912	.02601	.02464	.01848	.01232
94	.01335	.02984	.02833	.02733	.02421	.02110	.01972	.01357	.00741
$T_1 = 120°$	$t_1 = 50°$			70°			90°		
$t_2 =$ 112	0.05905	0.05754	0.05603	0.05503	0.05191	0.04880	0.04743	0.04127	0.03511
108	.05151	.05000	.04845	.04749	.04437	.04126	.03989	.03373	.02757
104	.04482	.04331	.04180	.04080	.03768	.03457	.03320	.02704	.02088

Double-Spray System at Middle West Oil Refinery
A typical September day

Hour	Temperature air, degrees F.	Relative humidity, per cent	Temperature of Water		Total cooling, degrees F.	Wet bulb temperature, degrees F.
			Before spraying, degrees F.	After second spraying, degrees F.		
7 a.m.	61	68	102	68	34	55
8 a.m.	65	56	102	68	34	56
9 a.m.	74	43	105	68	37	60
10 a.m.	78	39	107	68	39	62
11 a.m.	82	39	110	69	41	65
12 noon	86	42	113	69	44	69
1 p.m.	87	45	115	70	45	71
2 p.m.	86	50	116	70	46	72
3 p.m.	87	48	112	71	41	72
4 p.m.	88	43	123	72	51	71
5 p.m.	89	41	121	73	48	71
6 p.m.	87	45	120	74	46	71
7 p.m.	85	50	120	74	46	71
8 p.m.	83	56	119	75	44	71
9 p.m.	82	58	120	75	45	71
10 p.m.	80	64	122	75	47	71
11 p.m.	79	68	122	76	46	71
12 mid.	77	71	119	75	43	70
1 a.m.	76	74	117	76	41	70
2 a.m.	74	82	115	75	40	70
3 a.m.	72	86	114	75	39	69
4 a.m.	71	86	111	75	36	68
5 a.m.	71	86	110	74	36	68
6 a.m.	70	86	111	73	38	67

VI. FIRE-FIGHTING EQUIPMENT

This subject may be treated under two general headings, subdivided as follows:

1. Preventive or fixed equipment.
   (*a*) Structural or mechanical devices.
   (*b*) Electrical discharge dissipators.
   (*c*) Water, steam, and solution lines.
2. Fire-fighting or movable equipment.
   (*a*) Mechanical accessories.
   (*b*) Chemical engines.
   (*c*) Solutions.

Under the first division (*a*) may be included as permanent structural items: dikes, fire walls, traps, and all fireproof construction already discussed in preceding chapters. Fixed mechanical devices include special tank gas-relief valves, packed sleeves for swing

lines, gas-tight windlass boxes, etc.; automatic self-closing gage nipples, manplates, lantern roofs, doors, shutters, etc.; and for hot-oil lines, expansion joints, pipe bends and swings. Of the many forms of tank protective systems, particularly applicable to storage tanks with wooden roofs, the Cunningham is perhaps the best known. The principle employed is first to make the tank roof effectually gas-tight by the use of adhesive plastic cement in the sheet seams (employing a special joint between roof and shell); second, to conduct gases arising from the surface of the oil by means of a 4-inch pipe in the roof of the tank to a point outside of the tank dike; and finally to bond the roof electrically to the shell and thoroughly ground the tank itself. Special gas-tight, self-closing, roof hatches are included as a part of the system, which, it will be noted, is a combination of mechanical preventives and an electrical discharge dissipator, the idea being to prevent ignition by allowing the escape of gases and vapors only through the line mentioned, and then at a sufficiently safe distance from the tank, with the outlet further safeguarded with back-flash screens. The electrical bonding of the roof and shell of the tank and the grounding of the latter are intended to prevent the accumulation of a static charge which might cause a spark and ignite the contents. A gate valve or stop cock is placed in the vent pipe on the inside of the dike wall, so that gas may be shut off in case it becomes fired at the end of the vent. The tank roof is electrically bonded to the side sheets by heavy galvanized iron wires running from the apex of the roof over the galvanized sheeting to side sheets. The tank is itself electrically grounded by inch pipes, placed 180° apart, attached to the shell and driven to a suitable depth and imbedded in moist charcoal.

The grounding of an all-steel tank is not as simple as it may appear, it being particularly difficult to effect complete electrical dissipation through sandy soil. This may easily be proved by testing with an electroscope the end of an active pumping line which has been buried in such soil even to considerable depth. It will often be found that the leaves of the instrument diverge. Plates of steel 6 inches in width, riveted to the tank shell and driven 10 feet into the ground have offered thousands of ohms resistance to an electrical discharge, so that where possible, grounding pipes should be driven to a moist stratum. Other electrical dissipation schemes include a network of wires with drawing points strung immediately above the tank; but it is believed that a thoroughly tight roof and a well-grounded shell are equal to all other schemes for tank fire prevention.

Other mechanical devices, such as the lantern type of agitator roof previously illustrated, and metal clad self-closing fire doors (particularly serviceable for receiving and pump houses) all find needed application in refinery construction; while the proper provision for expansion in pumping-out, flow, and vapor lines constitutes a high type of preventive fire-fighting equipment.

For extinguishing an incipient blaze or flash, or fighting a fire that has spread, a series of water, steam, and chemical solution lines should be laid out in a systematic manner over the entire plant. The first-named are to be tapped to hydrants at strategic points, the second connected to all tanks, buildings, etc., and the third at least to all light-oil tanks (preferably all tanks), and further provided with attachment plugs at important centers. With respect to water fire lines, the same should be fitted up with extra heavy connections throughout, and should be continuous in circuit without a dead end. The line should be connected to separate high-pressure steam fire pumps, the latter preferably located in the boiler house for a small plant, or in a separate building at some central location for one of larger size. The pumps are to be used exclusively for fire fighting. All tanks, stills, agitators, etc., as well as the refinery buildings themselves, should be equipped with steam fire lines of adequate size. The latter are to be controlled by individual valves in prominently located groups, with the number of the tank, agitator, or building stenciled alongside in bright red characters.

In regard to lines and equipment for handling chemical fire-extinguishing solutions, the foamite system, as it is now installed in refineries, may be considered typical, and will therefore be described in some detail. It includes as principal features: two tanks for holding the reacting solutions, 10,000 to 50,000 gallons in capacity (the size depends on number, dimensions and type of the tanks to be served); a high-pressure twin duplex pump for handling the solutions; and a double system of distributing lines to the various tanks, agitators, etc., supplied. The solution tanks, preferably of white cedar) steel cannot be used for the " A " or aluminum sulphate solution), are erected at a central point, close to the fire pump house, where the foamite pump may be conveniently located; or when the latter is placed in the boiler house then the tanks should be adjacent thereto. The twin duplex pump is fitted with liquid ends of equal size, so that both fluids will be discharged in the same quantity, and is preferably of steam type, although a variable-speed motor-driven unit is permissible. The pump in each instance is manifolded to the solution tanks, mixing dump tank (employed to first dissolve chemicals), water supply and discharge mains, with provision for air agitation throughout the system. The distributing lines diverge from the mains at convenient points to supply the various tanks, individual twin lines for the larger tanks, and a manifold rack for the smaller sizes. The lines unite in mixing chambers which are hung on the sides of the shells and discharge into tanks at the roof edge. Control valves are located at the origin of branch lines, while hose attachment plugs are stationed at convenient points, the latter discharging separate fluids through parallel hose up to the distributing nozzle. The illustration, Fig. 12, page 21, gives a clear idea of a typical layout. Other forms of installation include mixing columns for large tanks or reservoirs, automatic release devices for small tanks, sprinkler systems, etc., but space does not permit their discussion. Somewhat similar distributing systems for solutions other than foamite have been employed in this country with varying success, but as they differ little in principle, further comment is unnecessary. Before the advent of chemical solutions for fire-fighting, fire-suction lines were employed in many of the larger plants; these comprised large-sized lines hooked up to special pumps for quickly emptying the tanks in case of fire. Such lines were often connected at the top of agitators, etc., so that when water was pumped in at the bottom the fire could be confined to the upper portion, and the damage sustained by the top rings only, as much oil being pumped out through the fire suction in the meantime as possible.

In movable equipment for fighting refinery fires many mechanical accessories are used, such items as hose, hose-carts, nozzles, shovels, picks, etc., being sufficiently familiar to require little mention. Other items not as widely recognized include valve forks, consisting of a long T-handled extra heavy pipe section terminating in a two-pronged fork by which a valve wheel can be turned at a distance of 20 feet or more; bevel-geared forks for turning valves inaccessible to straight forks, hooks, long-socket wrenches, cannon for firing solid shot, barrier shields for allowing near approach, protecting helmets, etc., etc. All of these are desirable and useful equipment for fire fighting.

Refineries also employ chemical engines in the form of small hand pumps for ejecting pyrene (carbon tetrachloride), carbonic-acid hand extinguishers of soda-acid type, acting automatically upon inversion, foamite pails, consisting of an outer cylinder for the bicarbonate foamite solution and an inner for the aluminum sulphate (fluids uniting as thrown) and the large soda-acid or foamite units mounted on wheels. The particular type of apparatus and number of units depend on the size of the plant, allowable investment and individual preference. In general, pyrene guns are suggested for office, chemical laboratory, and around electrical machines; while hand extinguishers of the soda-acid type located at easily accessible points in the various buildings are very desirable as emergency units. For service about stills, foamite extinguishers of hand or pail type, the latter especially for incipient flashes of broad area, will be found of

great value in obtaining an early control over fire. The larger chemical engines are desirable for plants not fully protected by standard foamite installations, for detached structures in general, or for obtaining a quick control over open fires instead of starting a large service pump and filling the main lines with solutions.

Of the various substances proposed from time to time for extinguishing oil fires, sand, carbon tetrachloride and aqueous solutions generating a heavy blanket of foam saturated with carbonic-acid gas have proved the most efficacious in refinery practice. Sand is exceedingly useful for extinguishing small incipient flashes around still heads, mannecks, safety valves, etc., and drums of sand should be kept in the rear of stills and on the bridge above, at convenient points for such purpose. Carbon tetrachloride as used in pyrene guns is a desirable solution for extinguishing small blazes in laboratory and office, since it leaves neither residue nor stain. For flaming arcs, caused by cross circuits, or other electrical fires where water or any aqueous solution would be likely to cause additional trouble, it is also highly efficient.

Tank fires, particularly where the roof has been blown off in the first explosion and the fire is unconfined, and in general, large oil fires, of an open nature, yield only to a blanket of carbonic-acid foam. Steam can be used with assured success under an absolutely tight roof and generally with little chance of failure under a moderately tight roof; but it is of little value when the latter is destroyed, for, as in the case of sulphur dioxide, sulphur dichloride, and other non-combustible products, volatilization is effected by the intense heat before smothering can take place. Carbonic-acid foam, on the other hand, resists the action of heat to such a degree that when properly distributed in proportion to the exposed area, the flame is completely vanquished in a few moments' time. Any soluble acid salt will liberate carbonic acid from bicarbonate of soda, but to build up a strong lasting foam is another matter. Solutions of glue or other viscous products have been used with success, but such solutions are very prone to bacterial decomposition and therefore the strength of foam produced is an uncertainty after the solutions are a few weeks old, particularly in summer weather. Various preservatives, such as boric acid, naphthol, arsenious oxide, etc., have been added to such solutions to prevent decomposition, while glycerine, quillaia bark, and saponin have been employed for replacing glue stock. None of these mixtures, however, has appeared to give such general satisfaction as foamite, a proprietary concentrated waste-licorice extract, which is unaffected by temperature changes and does not suffer bacterial decomposition. Typical formulae employed in the foamite system are as follows:

Solution A	*Solution B*
Aluminum sulphate, 13 per cent	Sodium bicarbonate, 8 per cent
Water . . . . .87 per cent	Foamite . . . . 3 per cent
	Water . . . . .89 per cent

Equal volumes of the above solutions, when mixed, will produce eight times the combined volumes of the liquids in foam, which expands and spreads rapidly over the surface of a burning liquid, and yet does not break down, each bubble being a high non-conductor of heat. On account of its relatively small water-content, foam produced as described above is probably the least injurious of all fire-fighting agencies, especially considering the quantities in which it is sometimes used. Upon drying, nothing is left but a white dust, which may be easily brushed off; and in the case of oil, the foam finally sinks through the oil like so much water, and may be drained off from the bottom.

With respect to deficiencies affecting the insurance rate, mention has already been made of minimum tank and building spacing distances, undesirability of wooden roofs, wooden stairs, exposed hatches, etc., and insufficient dike capacity. These are struc-

tural faults that should obviously have been avoided during plant erection. After the proper deficiency charges have been computed, and deductions allowed according to the class of oil carried, credits are figured on following basis.[1]

Credits (Preventive)

	Per cent
a. If entire premises are enclosed by tight fence at least 6 feet high.	2
b. Double hydrants within 300 feet of all parts of tanks (or group) on not less than 6-inch circulating main, or on branch main not less than 4 inches and not longer than 300 feet, laid below frost level where necessary, with water supply (unless with steamer service) sufficient to maintain a pressure of not less than 30 pounds, allowing a full flow through a 2½-inch outlet; with not less than 300 feet of standard 2½-inch hose and 1-inch nozzle, wrenches, etc., located on premises or in public fire department house within ½ mile.	5
c. Watchman registering hourly rounds on approved watch clock, nights, Sundays and holidays, and at all other times when plant is not in operation or open for business. . . . . .deduct	5
(Not cumulative with *d*.)	
d. Watchman registering hourly rounds nights, Sundays and holidays, and at all other times when plant is not in operation or open for business, with an approved combination watch and fire-alarm system reporting to central station maintaining runners' service for ascertaining causes of delinquencies. . . .deduct	10

(If without approved fire-alarm system with fire alarm at each watch box, reduce credit *d* 2 points.)

Credits (Extinguishers)

To be deducted from estimate after other credits have been allowed.

a. Steam jet in top of tank, fed by pipe of adequate size, but not less than 2 inches, with steam available at all times, approved arrangement.	10

NOTE.—Steam should be run into tanks if lightning storm is impending.

b. Approved foam chemical extinguisher system with solutions in storage tanks of adequate capacity and with approved pumping facilities.	20

Increase credit *b*, 5 points if there is no wood in tank roof or supports.

NOTE.—When all tanks of a group are not protected as above, prorate credits *a* and (or) *b* according to number of tanks so protected.

REFINERY OPERATION

I. GENERAL MANAGEMENT

In the operation of refineries there is considerable variation as to the methods employed, these obviously depending on the size of the plant and on the general business policy. Almost invariably a corporation form of control is chosen, although small skimming plants are often practically owned by one man who exercises the functions of president, sales manager, and superintendent. In plants of slightly larger size, or where a president has been elected as an expression of stock control, active management often devolves on a vice-president. The latter frequently serves as sales manager and secre-

[1] Selected from Rules for Estimating the Fire Hazard of Oil-tanks and Stills, Kansas Rating Bureau, 1919.

tary, being aided by one or two office assistants and a superintendent in charge of the plant proper. In small plants, where there are many diversified sales and considerable office correspondence, the president (or vice-president where the former is inactive) usually functions as general manager, handling the sales direct, and overseeing the refining policy in a general way. The details of the refining are entrusted to a superintendent. Correspondence of a general nature, purchasing of supplies, credits and collections are handled by an elected secretary, who also serves as treasurer, in plants of this class. Such a form of organization also includes an appointed sales manager and an elected treasurer where development of business warrants such a course, this arrangement being typical for the average moderate-sized plant. In the majority of refineries of this nature which are essentially one- or two-man institutions, the directors are mostly officers of the company. The board, as such, generally exercises little action other than to conform with the legal requirements of the corporation's franchise. The real authority lies with the president (or vice-president) and general manager. Organization on this order is illustrated in tabular form as follows:

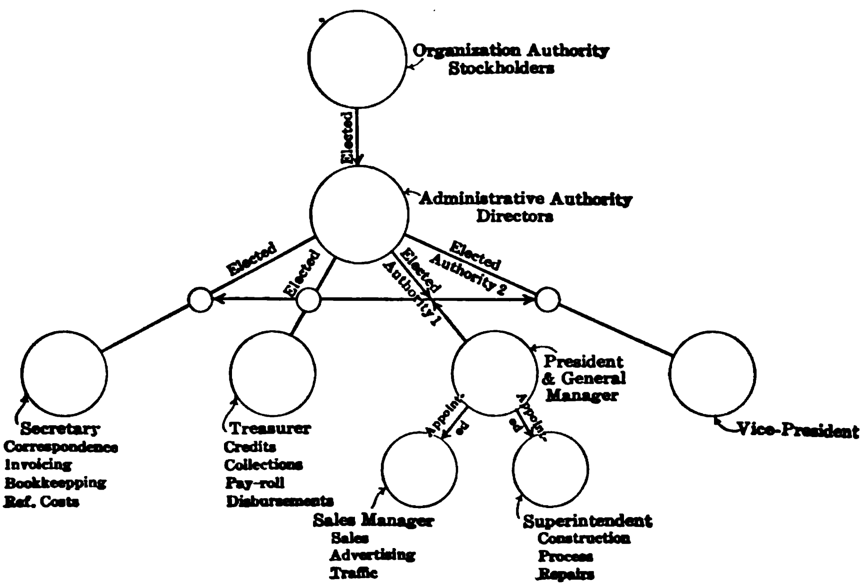


Fig. 148.—Small Refinery Management

In the next higher stage of development, the directors usually exert a considerable voice in the affairs of the company, although the president, vice-president, secretary and treasurer may be sufficiently heavy stockholders, as is frequently the case, to control their election and direct the general policy. Matters of moment, however, are decided by board action, and authority in general is more delegated as the size of the plant increases on the sales policy expands. When the general or sales officers are located at a distance from the refinery, or where the company operates more than one plant, a general superintendent is usually appointed who exercises control over the local plant superintendents in all matters pertaining to process and construction, he being himself responsible to the general manager of the organization. In a still larger scale of operations authority in all matters pertaining to plant control is often vested in a refinery manager, especially when the plant is remote from the general offices. This

official is often responsible for the crude supply, as well as for the quality of the finished products, refining costs and general plant upkeep. He is usually aided by a superintendent in direct charge of process and plant labor. The chief clerk is in charge of costs, statistics and local office force. The purchasing of supplies is often a function of the refinery manager and a certain responsibility for car records is demanded from his office; but the traffic manager himself is always located in the general, or sales offices, and is responsible only to the sales manager. As the extent of operations increases, or where the president has many executive duties, the refinery manager is usually responsible to an officer of the corporation with the title of "vice-president in charge of refining." A vice-president in charge of sales exercises equal authority in matters pertaining to his department. In the very large corporations there is often a manufacturing board, formed of the various managers and technical heads with a vice-president of the company as chairman. Such a group passes on refining costs, new processes and products, and matters of like nature.

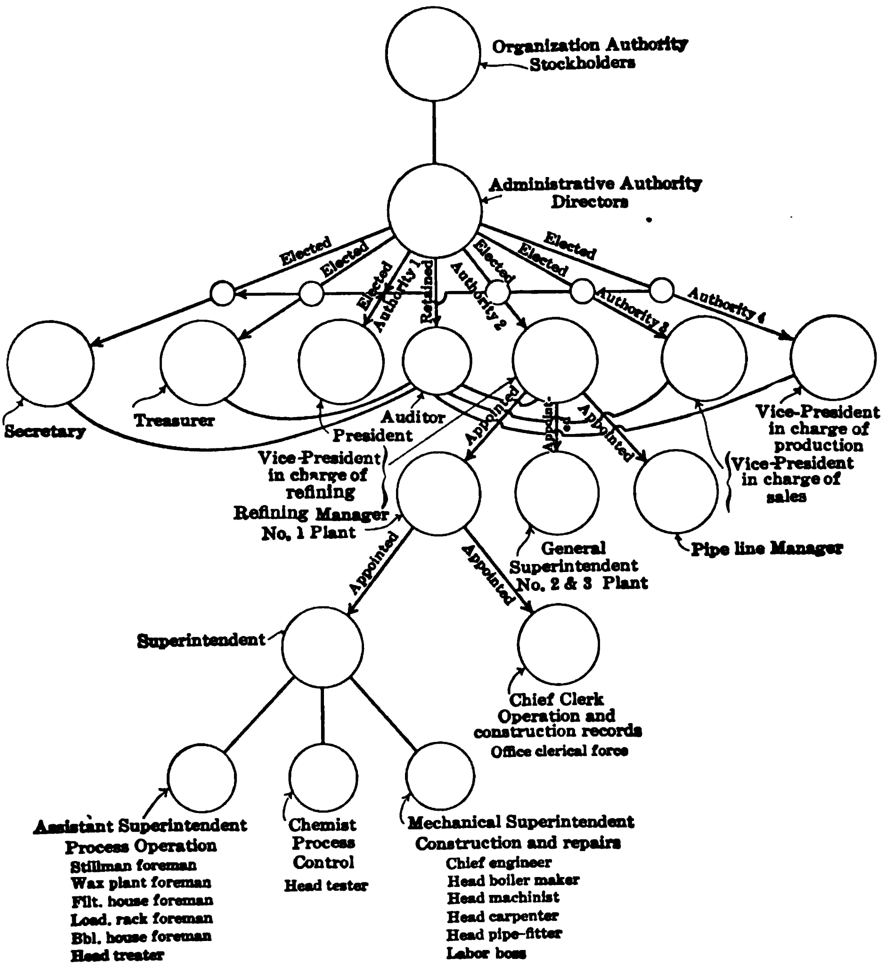


FIG. 149.—Large Refinery Management

Authority within a plant itself, of the type now under discussion, is usually delegated, as recently stated, to a superintendent and chief clerk. The former is aided by an assistant superintendent in charge of process and labor, a chemist responsible for process control only, and a master mechanic or mechanical superintendent in charge of repairs and construction. The several foremen or department heads, such as still foreman, wax-plant foreman, head treater, etc., report to the assistant superintendent; while the engineers and shop foremen, head boiler maker, head machinist, boss pipe-fitter, etc., report to the mechanical superintendent. The accompanying chart gives a comprehensive idea of the management of a large refinery, delegated through the various officers of the corporation and their appointive heads, the scope of authority within the plant itself being shown in some detail.

In a plant organized as above, the refinery manager generally establishes the wage schedules for the works, labor and clerical force, while the superintendent and chief clerk determine the actual number of men required to operate their departments. The number of employees in different plants of the same crude capacity will vary widely, according to the nature of the crude, the process employed, the layout and physical condition of the plant, the amount of operating and construction cost data required by the general office, to say nothing of the personal efficiency equation of the men in charge. While it is obvious that no fixed rule can be given in such matters, recent developments in the petroleum industry have demonstrated that considerably reduced forces both in plant and office have increased rather than decreased the general plant efficiency.

Because a large plant needs an assistant superintendent to look after the process and a mechanical superintendent for construction and repairs, it does not follow that such organization is necessary for a plant of moderate size where the department foremen may profitably report directly to the superintendent. Without in any way reflecting on the high-class research carried out in many of the larger plants, it may be stated that a painstaking accurate tester will frequently serve a plant of moderate size with more efficiency than the so-called research often practiced, which in reality is very frequently the rediscovery by a technically trained man of facts well-known to the experienced refiner. Again, a large clerical force employed in collecting and compiling data of refining costs and other statistical information, more or less ignored in the sales campaigns, adds little real efficiency to plant operation; and while no one will gainsay the importance of accurate cost and yield data, there is such a thing as over systematization. In times of profit these features are apt to pass unnoticed; but they are the first points of attack in periods of depression. The ideally operated plant is that which runs with a minimum number of employees, where costs can be determined beforehand with sufficient accuracy and the process possesses such a degree of flexibility that no large quantities of unsalable or profitless products will accumulate. Such a condition obviously requires a well laid-out and well kept-up plant, as well as an exceedingly close relation between operating and sales departments.

II. GENERAL REFINING PROCESSES

The processes employed in the separation of the various constituents of crude petroleum or "crude," into marketable products [1] are many and varied, and while often apparently complex in nature, can be ultimately resolved into one or more of the basic refining methods listed below, or else fall under the head of allied operations, such as blending, compounding, grease-making, distilling, etc. These latter are not strictly refining processes in a purely technical sense, but are all incidental to the general operation of a refinery.

[1] Gasolines, naphthas, distillates, kerosenes, gas oils, neutrals, paraffins, wax, cylinder stock, coke, etc.

Basic Oil-Refining Methods

(a) Fractional distillation.
(b) Chemical treatment.
(c) Cold pressing.
(d) Fractional fusion.
(e) Cold settling.
(f) Decolorization.
(g) Cracking.

Fractional distillation, distilling or "stilling," as it is often termed, may be defined as the separation by volatilization of one group of petroleum constituents from another, in some form of closed apparatus, by the aid of directly or indirectly applied heat. Except in the case of a few unimportant crudes,[1] it is universally practiced, and is the most important art in the whole scope of refining. Distilling methods may be classified according to the following tabulation:

Fractional Distillation Methods

I. Distillation by Dry Heat

(a) Topping, skimming or stripping:
- (1) Crude (overhead; benzine, distillate, gas-oil), to reduced crude, fuel oil, tar.

(b) Coking:
- (1) Crude (overhead; benzine, distillate, gas-oil, paraffin distillate) to coke.
- (2) Reduced crude tar (overhead; distillate, gas-oil, paraffin distillate) to coke.
- (3) Paraffin slop (overhead; gas-oil, paraffin distillate) to coke.

(c) Rerunning:
- (1) Light ends (overhead; turpentine substitute, naphtha) to distillate.
- (2) Heavy ends (overhead; burning oil distillate) to gas-oil.

(d) Sweetening:
- (1) Sour distillate (overhead; sweet naphtha, distillate) to gas oil.

(e) Cracking:
- (1) Gas-oil (overhead; converted distillate, benzine) to gas or fuel oil.

II. Distillation by Steam

(a) Steam stilling:
- (1) Crude benzine (overhead; gasoline, naphtha) to distillate.
- (2) Untest distillate (overhead; benzine, naphtha) to test distillate.

(b) Reducing:
- (1) Crude (overhead; benzine, distillate, gas-oil, wax distillate) to flux steam-refined stock.
- (2) Reduced crude (overhead; distillate, gas-oil, wax distillate) to flux steam-refined stock.
- (3) Pressed distillate (overhead; gas-oil, lubricating cuts) to heavy lubricating stocks.
- (4) Overhead lubricating cuts (overhead; gas-oil, lubricating cuts) to light lubricating stocks.
- (5) Wax distillate (overhead; gas-oil, wax-oil) to fuel oil.
- (6) Wax distillate (overhead; gas-oil) to reduced wax distillate.

[1] Certain "natural" lubricating crudes after filtration serve as light engine oils or general lubricants. They are few in number, Smith's Ferry crude being a typical example.

(7) Wax distillate and rod wax (overhead; distillate, gas-oil) to petrolatum stock.

(c) Cracking:

(1) Gas-oil, fuel, flux (overhead; converted distillate) to fuel oil, flux.

Distillation by Dry Heat

While the terms "topping," "skimming" and "stripping" are used somewhat interchangeably among the oil fraternity, the first-named may be applied more correctly to the process of removal by distillation of the comparatively small percentage of benzine or light engine distillate from the heavier crudes, i.e., the removal of the "tops." Skimming, in its narrower limitation, implies the removal of somewhat greater percentages of overhead distillates, i.e., in addition to the benzine content, all of the kerosene fraction and often part of the gas-oil. The term "skimming" is particularly applicable to the operation of scores of plants throughout Oklahoma and Texas. Stripping may be held to mean a complete removal of all light fractions down to those of lubricating value, and represents the initial refining process, generally employed to-day by those plants which later further reduce the residuum first obtained to lubricants, flux, or coke. Topping, skimming, and stripping are now generally accomplished by some form of tower still, or continuous-distillation process, but prior to 1906 stripping was, with certain important exceptions, essentially a discontinuous batch still operation; and although a history of the development of the refining industry is outside the scope of this article, it may be well to discuss the conditions at that period, as throwing light on the subsequent marked changes in process occurring shortly afterwards.

Livingston [1] had already perfected a continuous scheme of distillation as early as 1899, and Frasch [2] had developed his "compound" sweetening process to a high degree of efficiency. Both of these processes were in somewhat general use at the refineries of the Standard Oil Company, but obviously not in the industry at large. Even in the refineries mentioned, continuous distillation had not supplanted batch stills to any decided extent.[3] A considerable portion of high-grade Pennsylvania crude was, even at this late date, run dry in batch stills to 10½ per cent tar, while practically the entire production of the Lima field was also so handled (25 per cent tar). In each instance fires were slackened when "off-natural" water-white was used to effect an increased percentage in burning-oil distillate, in accordance with the early discovery of Silliman.[4] The following tabulation gives an idea of the yields and cuts employed at the period mentioned:

[1] See U. S. Patent 728,257, May 19, 1903.

[2] Address by Herman Frasch, published Jour. Ind. Eng. Chem., 4 (1912), 134; U. S. Patents 378,246, Feb. 21, 1888; 448,480, March 17, 1891: 487,119, Nov. 29, 1892.

[3] Steam-stilling, heavy-end rerunning, and reduction of Texas crude was effected in batteries of continuous stills, but the great bulk of crude handled was still stripped in batch stills at the period mentioned.

[4] See Silliman, Am. Chemist, 2 (1871), 18 and 20; Peckham, Am. Jour. Sci. (2), 47 (1869), 9; and Leet's "Petroleum Distillation," New York, 1884. Leet is authority for the story of the accidental discovery of "cracking," see page 427. This discovery led to further experiments, resulting in the knowledge that a portion of the distillate had become condensed through contact with the relatively cool upper shell of the still, and, dropping back into the hot residuum, had become dissociated into distillates of lower molecular weight and boiling point. From this period practically up to the advent of tower stills, the upper shell surface in still settings was left uncovered, so that the partial condensation previously described would occur and increase the yield of the more desirable kerosene fractions.

Average Yield of Pennsylvania Crude Distilled to Tar

(As refined in batch stills, 1906)

Cut	Grade	Yield, per cent
Over 69	"P.C." naphtha	6.0
69–54	Light standard white distillate	20.0
54–43 (hold 7 hours)*	Water-white distillate	28.0
44 (hold 7 hours), 10.5 per cent tar	Heavy standard white distillate	33.0
Bottom 10.5 per cent tar	.....	10.5
	Stilling loss	2.5
	Total	100.0

* In the typical yields above, the better quality of burning-oil distillate was off at 43° Bé. Fires were then banked and draft reduced by choking the dampers of the side flues with which many of the stills were equipped at that period, thus causing the stream from the worm to decrease from 30–40 barrels per hour to 7–10. The distillate now began "cracking" and often rose as high as 46–47° Bé., accompanied by the production of a considerable quantity of gas, which was burned under stills. This, it will be recollected, was before the days of compression systems or of acute demand for gasoline. The cracked distillate produced was of inferior quality and it was always cut to "standard white," a second-grade oil, thus bearing out the statement of Veith's "Das Erdol," 1892, that distillate produced in uncovered stills varied in composition from the natural oils originally present in the crude, and that it was also of inferior quality.

Average Yield of Lima Crude Distilled to Tar

(As refined in batch stills, 1906)

Cut	Grade	Yield, per cent
Over 54	Sour standard white distillate	10.0
54–43 (hold 7 hours)	Sour water-white distillate	30.0
43 (hold 7 hours), 25 per cent tar	Sour standard white distillate	33.0
Bottom 25.5 per cent tar	.....	24.5
	Stilling loss	2.5
	Total	100.0

Subsequent distillation of the residuum or tar was carried out in stills provided with many feet of aerial condensing worm, leading from various expansion drums which were piped to separate condensing coils, thus obtaining a very fair separation of the overhead distillates, with the saving of much needless rerunning. It might be further stated that at this period refining engineering had already begun to assume considerable importance. The standard 40 foot by 40 foot horizontal, cylindrical still of to-day had already been perfected, the column form of setting had become fairly general and the old-style wooden condensers had disappeared. Several circumstances had a far-reaching effect on the industry at this time; they were: (*a*) the invention of the Van Dyke and Irish [1] tower still, (*b*) the gradually increasing demand for gasoline,

[1] See United States Patents, 1,095,438, May 5, 1914; 1,143,466, June 15, 1915; and pp. 214 and 216 this volume.

due to the beginning of intensive development of the automobile industry, and (c) the discovery of extensive pools of new crudes, containing large quantities of gasoline and kerosene. With the advent of the tower still which completes the distillation of crude from benzine to coke in one operation, the old stripping process to dry-run tar was gradually supplanted, and is now practiced only in a few sections of the country. The increasing demand for gasoline began to stimulate research, which led to the invention of the Burton still, while the discovery of new fields of production, particularly that of the Illinois pool, did much to systematize refining and to develop modern plant capacity. The discovery of this crude, with its high gasoline and kerosene content, put an end to the necessity of running Pennsylvania crude to tar, and this process became obsolete. Additional impetus was given to the development of tower stills to take care of the increasing crude production. The clean quality of the Illinois crude and its freedom from deposit favored continuous stripping, a method which was more and more generally adopted with the discovery of the large Mid-Continent pools. It is almost universally employed to-day either in its entirety, or in a skimming modification.

Stripping, skimming, or topping, as practiced to-day,[1] is generally conducted either in standard, horizontal, cylindrical stills, connected for continuous running, or in some form of tube stills. The lighter crudes are usually skimmed or stripped in standard stills, occasionally dry-run, but generally with a small amount of bottom steam, so as to agitate the still contents gently and prevent the deposition of coke, as well as to enable the distillation to proceed more smoothly and with less expenditure of directly applied fuel. The stills used for this purpose vary from 36 inches in diameter by 15 feet to units 14 feet in diameter by 40 feet long. They are usually connected in battery by flow lines in some modification of the original Livingston process. It is common practice in this country to connect six or seven stills in a circuit; foreign usage favors a greater number.[2] Certain recent installations have comprised continuous equipment erected in receding elevation;[3] but in general a continuous battery of stills is built at grade, and flow is secured by connecting lines which leave successive stills at regularly decreasing levels. A charging and a pumping-out pump control the first and last stills respectively. Each still of the series is provided with by-pass valves, so that it may be cut out of continuous service and run down to fuel, or pumped out and cleaned, as occasion requires. When the still is running, the bottom should be inspected frequently; dark spots appearing on an otherwise uniformly colored bottom indicate that cleaning is necessary.

Some form of heat-exchanging or settling still, previously described,[4] is invariably employed with a battery of continuous stills. Water, mud, etc., are removed in this still and damage to the bottoms of the succeeding units is thus prevented. This still also effects a decided saving in fuel. A properly designed exchanging still frequently runs a considerable stream of high-gravity benzine or gasoline. Where dephlegmation towers

[1] For a further discussion of the subject of continuous distillation, the reader is referred to Jacobi: Dingler's polyt. Jour., 159 (1861), 150; Fuhst: Idem, 207 (1873), 293; Gaster: Pet. Review, 1 (1899), 465; von Grolling: Idem, 2 (1900), 130. U. S. Patents have also been granted to Stombs and Brace, Tait and Avis, Hill and Thum, Van Syckel and others, involving various claims now of mainly historical interest; a somewhat detailed description of them occurs in Bacon and Hamor's American Petroleum Industry, Vol. II, 543. For continuous types of tube stills, see p. 328 in this volume.

[2] Russian practice (Nobel Brothers) includes fourteen to sixteen stills in circuit; Austrian and Rumanian somewhat less. For additional information, see Gadaskin and Popich: Jour. Russ. Phys.-Chem. Soc., 44, 1715; Veith's "Das Erdol," 1892; Pet. Ind. Tech. Rev., 2, 130; Bacon and Hamor's American Petroleum Industry, Vol. II, 550. For a description of the process of Edeleanu, see p. 391 of this volume.

[3] Note the setting of stills in battery (Reducing Stills for Refining Mexican Petroleum), p. 80.

[4] See pp. 148 and 184.

are used in connection with continuous stills it is frequently possible to produce practically water-white overhead products. This is especially the case with light-gravity crudes of low sulphur content. Often these products are within market specifications, or require a slight "doctor" treatment, with only an occasional use of acid. The gravities of the streams from the several stills or towers in circuit are dependent on (*a*) the gravity and composition of the crude oil, (*b*) the speed of flow of the latter through the series, and (*c*) the extent of firing of the individual stills. It is the objective of the efficient refiner to process the maximum amount of crude oil in a given period, and at the same time to obtain overhead distillates of close distillation range, requiring a minimum of re-running. As typical values, the working gravities of the streams from one 600-barrel exchanging and six 1000-barrel stills, connected in a battery, and running 9000 barrels of 37° Be. gravity Oklahoma crude daily, are tabulated below. It is to be understood that such gravities will vary considerably according to the nature of the product desired by the refiner at the particular time of operation.

Typical Gravities from Continuous Stills when Stripping Oklahoma Crude

Stills	Gravity, Baumé degrees	Products
Exchanging	62–64	Light benzine or gasoline
No. 1	56–58	Light benzine or gasoline
No. 2	50–52	Heavy benzine or naphtha
No. 3	46–48	Heavy benzine or naphtha
No. 4	42–44	Water-white distillate or burning oil
No. 5	38–40	Rerun distillate or prime-white distillate
No. 6	34–36	Gas oil

In general the still which is running water-white distillate or kerosene, i.e., No. 4, is used as the balance of the series. The gravity is not only held to close limits, but the fire test is maintained at 150° F. as well; while the lighter benzines or gasolines are distilled at a speed that will maintain a minimum of heavy ends. Stills 2 and 3 therefore require the hardest firing; the quantity of distillate at this point together with the maintenance of proper test distillates usually determines the amount of crude of any given grade that it is possible to process during a unit period of time.

When a small quantity of overhead products is to be distilled off, four stills in the battery suffice. The following gives an idea of the running gravities for Texas crude of 22.0° Bé. An interesting feature of this process is the fact that in addition to the production of distillate, the second and third stills of the series continuously give off a practically pure hydrogen sulphide gas, which appears to be not the result of cracking, but rather due to formation from the excess sulphur [1] carried by the crude in physical solution.

[1] The sulphur content of 22.0° Bé. crude varies from 0.80–2.50 per cent. Often "B.S." from this crude will contain a high percentage of elementary sulphur, apparently precipitated from solution. Notwithstanding its high sulphur content, from 1½ to 4 times as great as that of Lima (i.e., 0.65 per cent), Texas crude is much less resistant to sweetening methods than the latter, much of its sulphur passing off as hydrogen sulphide gas during simple reduction. Lima crude only gives up its sulphur in such form at cracking temperatures and then in limited quantity.

Typical Gravities of Distillate from Continuous Stills, Skimming Texas Crude

Stills	Gravity, Baumé degrees	Products
Exchanging	54–56	Naphtha
No. 1	52–54	Naphtha
No. 2	42–43	Sour distillate
No. 3	36–37	Heavy end
No. 4	31–32	Gas oil

The amount of fuel consumed in skimming or stripping is dependent on (*a*) gravity of crude, (*b*) percentage of distillation, (*c*) quantity of steam used, (*d*) extent of dephlegmation practiced, (*e*) furnace design, and (*f*) efficiency of shell insulation. It varies from 2 to 8 per cent by volume of crude refined, 4.5 per cent constituting an average value. A battery of continuous stills is illustrated below.

FIG. 150.—A battery of continuous crude stills.

Skimming is also accomplished by continuous tube stills, where the process, as before remarked is usually termed topping. Such stills are described at length in the section on refinery construction. While theoretically any grade of crude may be run in a tube still, it is general practice to limit the application of such stills to the heavier grades of crude which contain so much water that distillation in the ordinary standard form of stills would be an impossibility on account of foaming and boiling over of contents. Tubular stills, being highly efficient in fuel economy, are particularly adaptable to heavy crudes which require the heating of a comparatively large volume to obtain a relatively small quantity of distillate. For the reasons just cited this type of still is practically universally used in the refining of Californian and Mexican crudes, where various kinds of tube stills are employed.

In the simpler forms of tube stills,[1] the entering crude, preheated by travel through a heat-exchanging unit, is raised to distillation temperature by passing through a con-

[1] For a description of the construction of the present general types of tubular stills, see p. 148, this volume. A detailed description of the important topping plants in California is given by A. F. L. Bell, in the Bulletin of the American Institute of Mining Engineers, 1915, No. 105, 1769–90; J. M. Wadsworth, U. S. Bureau Mines, 162, 1919. Processes and plants devised by Bell, Burroughs, Dyer, Brown, Pickering, Fuqua and Trumble are described at length.

tinuous coil, and discharges into a vertical dephlegmating tower or evaporator, or in some instances into a horizontal drum provided with film plates. Here the naphtha and distillate vapors separate themselves from the heavy residuum, proceed upward to the top of the tower, and are condensed in the usual manner. The residuum drops to the bottom of the evaporator, and is pumped away in a continuous discharge. In the more intricate types of tubular stills, the overhead distillates pass through a series of dephlegmating and condensing units, and are finally resolved into streams of various gravities, as in the separation obtained in standard practice, although generally with a much closer range of boiling points. The details of such a distillation process, widely operated on the Pacific coast, i.e., the Trumble Process, are described at length in the section on special refining processes.[1]

Skimming is practiced to a very considerable extent in the Southwest. The residuum is either marketed directly as fuel oil, or is further steam-reduced to flux or lubricating stock. Topping is in general vogue on the Pacific coast, but coking is more generally applied to crudes of intermediate gravities that will produce good yields of paraffin distillate, and in localities where coke[2] will bring a high market price. Coking plants to run at a profit, must also have a low freight rate on steel plate, and be equipped with heavy bending rolls, or be in proximity to mills or shops which possess them. In short, refineries in which coking is part of the regular routine generally operate on Kentucky, Lima, Illinois, Kansas or Mexican crude, and are located close to great industrial centers or export points. They carry a heavy investment, not only in distilling equipment, but in boiler and repair shops. While soft fuel coke may be produced from steam-run crude, dry coke is only obtainable from crude reduced with a minimum of steam, or from dry-run tar. As previously stated, this latter source of coke was in almost universal use some ten or fifteen years ago. Now tar stills have in the main been superseded by tower stills, in which crude is either coked direct without steam or reduced (with a minimum of steam). This produces the usual line of light overhead distillates, as well as the heavy lubricating fractions, without the loss of heat in the transfer of the residuum that took place in the older method. However, as tar stills continue to be used in a few plants, a short description of the present-day process may not be out of place. Where tar stills are employed, crude is distilled without steam in a standard horizontal cylindrical crude still, and is stripped through kerosene and a part of its gas-oil. The residuum, usually amounting to 20 to 30 per cent with a gravity of 20 to 24° Bé., is settled[3] for several days, or in some instances acid-treated,[4] and then transferred to tar stills, usually of comparatively small capacity, i.e., 250 to 500 barrels. Here the tar is rapidly distilled so that there is a constant drop in the gravity of the stream, the overhead distillates often being condensed in separate worms, but without the degree of dephlegmation formerly practiced. This is perhaps not so necessary with the modern method of running to tar. The stillman watches the color of the stream, and is largely governed by it in making cuts from paraffin distillate to slop which must be rerun a second time to be suitable for pressing. Very soon the gravity of the stream begins to drop rapidly, the still bottom shows red, the stream is cut to " gum "[5] or " wax tailings " and the firing is continued for some twenty or thirty minutes longer, or until the still is coked.

[1] See p. 146 for construction details, p. 385 for method of operation, this chapter.

[2] See p. 330.

[3] While the entire sensible heat of the tar is frequently lost in the settling process, the operation taking from one to seven days to completely free from suspended carbon, coke, etc., the prolonged life of still bottoms, due to settling, more than compensates for the loss sustained.

[4] See p. 371.

[5] The substance designated as "gum," "still wax," and "wax tailings" is one of the few petroleum products heavier than water. Its appearance in the distillate, together with a dense yellow fume escaping at the safety valve, is a sure warning to the stillman that the still is about to coke. The composition of wax tailings is complex, containing hydrocarbons of high molecular weight and decom-

In the operation of tower stills,[1] the procedure at first resembles the operation of the simple horizontal cylindrical crude still, except that the vapors pass through a heavy and intermediate tower,[2] where the heavy-boiling-point fractions are dropped out and returned to the still through a valve-controlled run-back line. The lighter naphtha fractions pass on and out of the second or intermediate tower, and thence are condensed by the light worm.[3]

With towers varying in design from tubed vertical drums to exposed and air-jacketed tubes expanded into headers, cross drums, etc., control methods for tower stills differ considerably. A somewhat general practice, however, is to close the run-back from the second or intermediate tower to the still, and open to the intermediate worm, when the stream of the light worm is off heavy naphtha, or about 50° Bé. gravity. The intermediate worm now begins to run burning-oil distillate, the light worm continuing to flow a small stream of naphtha, which has now increased in gravity. Similarly, when about off water-white distillate, the heavy tower run-back is closed, and the tower is opened to the heavy worm,[4] which now begins to run gas-oil, while the second or intermediate worm runs heavy burning-oil distillate, and the light worm naphtha as before, but in an intermittent stream. Shortly after this point the fires are increased, and paraffin distillate shortly makes its appearance. It flows from the heavy worm, while gas-oil flows from the intermediate worm, and cracked naphtha accompanied by a considerable quantity of gas, from the light worm. This condition prevails throughout the balance of the run, or until the paraffin distillate becomes too poor in quality (color) to warrant sending it to the distillate tank. It is then cut into slop for further rerunning. The stillman now watches the gravity of the heavy worm very carefully, also the condition of the still bottom. As soon as signs of tailings appear, the " gum line " is opened. This usually leaves the vapor line prior to its entrance into the heavy tower.

Coking,[5] as in the case of tar stills, takes place some twenty to thirty minutes after " tailings " appear. The whole operation consumes about forty odd hours, this interval varying with the nature of the crude, the design of the stills, the method of firing, and the cuts employed. The first tower stills were end-fired, coking being aided by burning the gas evolved, directly under the still. On account of the difficulty of securing uniform heat, end-fired stills have largely given place to the side-fired variety, two in battery.[6] Where coal is used for fuel there has been in more recent installations, a return to end-fired stills, with built-in mechanical stokers,[7] is practiced with great apparent success.

position products of the latter (anthracene and chrysene) coke, etc. It is usually semi-asphaltic in nature and rapidly darkens on exposure to air from yellow to dark brown. It finds application in impregnating and insulating compounds. A typical inspection follows:

Source	Sp. gr.	Lbs. per gal.	Fl.	B.	Visc./212	Sol. CS_2
Tar still............	1.140	9.4962	365	465	302	.096
Tower still.........	1.106	9.2130	385	485	210	.055

[1] See p. 216.

[2] See p. 221.

[3] See pp. 163 and 180.

[4] Same as (3).

[5] Still coke varies in thickness from about 10 to 18 inches when running Lima, Kansas, or Illinois crudes in the type of still just described. While several mechanical devices have been suggested to aid in its quick removal, the process is still largely one of hand labor, using spud bar and shovel. On account of its low compression strength (i.e., 60 pounds), its use for metallurgical work is limited. It finds its chief application in the manufacture of battery carbons. A typical analysis follows: Still coked at 890° F.; volatile carbon, 3.15; per cent fixed carbon, 95.73 per cent; sulphur, 0.97 per cent; and ash, 0.15 per cent.

[6] See Fig. 128, p. 232.

[7] See Fig. 130, p. 234; Fig. 131, p. 235.

The following process tabulations give results obtained under actual working conditions on Lima and Indiana crudes, and may be considered as typical for discontinuous crude tar, and tower stills:

Typical Yield of Lima Crude Oil Distilled to Tar

(Charge 1260 barrels, 34.6° Bé., crude, run dry in horizontal cylindrical crude still to tar, 37 hours, 20 minutes, running time)

Cuts	Gravity, Baumé degrees	Grade	Yield, per cent
Over-clear worm....	....	Slop....	0.89
Clear worm, 52.....	57.5	Sour naphtha....	15.59
52–40....	42.3	Sour water-white distillate....	22.21
40–tar....	36.8	Sour prime-white distillate....	37.15
Bottoms....	22.3	Tar....	21.14
		Stilling loss....	2.92
		Total....	100.00

Typical Yield of Indiana Tar Distilled to Coke

(Charge 298 barrels, 22.6° Bé. tar, run dry in cylindrical horizontal tar still, 14 hours 30 minutes running time)

Cuts	Gravity, Baumé, degrees	Grade	Yield, per cent
Over 29.5....	32.5	Gas oil....	11.42
29.5–20.0 (color)	27.6	Paraffin distillate....	62.71
Color 20–20.0 gum.	19.1	Slop....	7.72
Gum coke....	9.3	Gum....	1.39
		Coke....	10.45
		Stilling loss....	6.31
		Total loss....	100.00

In the operation of tower stills great care must be exercised in coking, on account of the large area exposed; the frequent replacement of still bottoms of this size is a heavy expense, not only from the standpoint of repairs, but from that of idle equipment. It is possible to charge a tar still and make a safe run when the still is in a condition that would be dangerous for charging crude. Moreover, the cost of construction of a tower-still battery is heavy, and the operating labor cost is also higher than for batch stills. However, under proper supervision, many runs may be coked without serious detriment to the bottoms, and the increased labor and investment cost may be more than offset by the complete abolition of the tar stills, so that a comparison of the tables of yields, together with the fuel economies listed on page 333, shows conclusively the advantage of the tower stills over the old system of running to tar and redistilling the latter.

Typical Running Card and Yield of Lima Crude Distilled to Coke

(Charge 1260 barrels, 34.6° Bé. crude, run dry to coke in a horizontal cylindrical tower still, equipped with heavy and intermediate towers. Firing time 51 hours 40 minutes, running time 43 hours 30 minutes.)

Started charging, 10:25 a.m. Fired, 10:55 a.m.
Charged, 10:50 a.m. Over, 8:00 p.m.

Hour	Light Worm			Intermediate Worm			Heavy Worm		
	Cut	Gr.	Grade	Cut	Gr.	Grade	Cut	Gr.	Grade
9 p.m.	Over-off...	68.5	S. naph.	Over 40, s.			Over 31,		
12 a.m.	S. naphtha.	60.0	S. naph.	w.w. dist.;			gas-oil;		
3 a.m.		55.0	S. naph.	40–37, s.p.			31–18,		
6 a.m.		52.5	S. naph.	w. dist.;			paraffin		
9 a.m.	Note.—At	51.9	S. naph.	37–30, gas-			dist;. 18–		
12 m.	50° light	48.1	S. naph.	oil; 30–off	46.1	S.w.w.d.	gum, slop;		
3 p.m.	worm, cut			paraffin	44.2	S.w.w.d	gum-off,		
6 p.m.	int.* worm			dist.	43.0	S.w.w.d.	gum		
9 p.m.	to rec.			Note.—At	41.2				
12 m.	house			40° int.*	40.1				
3 a.m.				worm, cut	39.4	S.p.w.d.		35.0	Gas oil
6 a.m.				h. worm to rec. house	41.4	S.p.w.d.		34.5	Gas oil
9 a.m.		62.6	S. naph.		38.4	S.p.w.d.		32.9	Gas oil
9.30 a.m.		53.2	S. naph.		33.7	Gas oil		30.8	Paraf. dist.
11 a.m.		43.7	S. naph.		32.0	Gas oil		28.0	do.
12 m.		43.7	S. naph.		32.0	Gas oil		26.0	do.
1 p.m.		43.7	S. naph.		31.0	Gas oil		24.0	do.
1.30 p.m.					30.0	Paraf. dist.		22.5	do.
2 p.m.					29.0	Paraf. dist.		20.0	do.
3 p.m.					28.0	Paraf. dist.		16.0	Slop
3.30 p.m.					27.0	Paraf. dist.		9.0	Gum

* Intermediate.

Yield

Grade	Gravity	Per cent
Sour naphtha	57.8° Bé.	19.22
Sour water-white distillate	42.4° Bé.	25.10
Sour prime-white distillate	38.2° Bé.	21.55
Gas oil	34.5° Bé.	10.56
Paraffin distillate	28.9° Bé.	12.95
Heavy slop	17.8° Bé.	2.34
Gum or tailings	8.9° Bé.	0.31
Coke	......	4.71
Stilling loss	......	3.25
Total	......	100.00

Comparison of Fuel Economy with Batch and Tower Stills Running on Kansas Crude of 37.8° Bé., Coal as Fuel

Batch stills (side flues) *	Quantities	Tower stills
1,260 barrels	Crude charged	1,280 barrels
38,050 pounds	Coal burned †	42,880 pounds
12,830 pounds	Ash produced	12,600 pounds
33.7 per cent	Ash, per cent as fired	29.3 per cent
22.76 per cent	Ash, per cent, laboratory test	22.76 per cent
30.2 pounds	Coal burned per barrel of crude run	33.5 pounds
Tar stills		
7.6 pounds	Proportional equivalent coal per barrel run (35.0 lbs.×23%×95%) ‡	0.0 pounds
37.8 pounds	Total coal equivalent per barrel crude run to coke	33.5 pounds

* Additional fuel tests not included in this volume have demonstrated the saving of 12 to 15 per cent by side-flue equipped stills over the standard setting; hence the superiority of the tower still is the more apparent in the succeeding figures. The furnace gases in the side-flue still passed under the shell, upward through vertical flues, built in side walls close to the rear end of the still. and back to the front end through a covered passage about 3 feet 6 inches high, built over the lugs. At the terminus of this passage a steel stack was erected. It was subdivided into two flues for stills in battery, and was provided with double dampers for final exit of spent furnace gases. With the introduction of the tower still, the side-flue still gradually sank into disuse.

† In the coal burned, there is also included a certain amount of gas produced during the cracking period of the run. This gas, however, is not generally turned under the still until the heavy worm is about out of paraffin distillate, and rarely represents in coal equivalent more than 1000 pounds for a 1000-barrel still.

‡ The proportional equivalent of coal per barrel of tar distilled is computed on the basis of 23 per cent yield of tar from batch stills, 5 per cent loss for settling, and the equivalent of 35 pounds of coal per barrel allowed for stilling. Since refuse slop, acid oil, agitator coke, etc., are usually burned under tar stills together with coal; exact fuel values are obtainable only with difficulty, but the above may be considered a fair average.

Running Time and Fuel Consumption, by Periods on Oklahoma Crude, 38.3° Bé., to Coke, on a Charge of 1268 Barrels

Period	Running time, Hours	Minutes	Fuel consumption, pounds coal
Fire-over	3	55	5,700
Over-paraffin distillate	21	30	28,270
Paraffin distillate to gas	8	30	3,410
Gas-off	14	30	3,920
Gas-off *	..	..	750
Total quantities	48	25	42,050

* See note (†), this page; in this instance the gas equivalent computed at only 750 pounds of coal.

Where overhead distillates are improperly separated, as evinced by distillation tests, or are of poor color, or of heavy sulphur content, they must be rerun. This is usually accomplished in an ordinary standard horizontal cylindrical crude still.

If gasolines of special fractionation range, solvent naphthas of definite flash test, or turpentine substitutes are required, the stills are usually equipped with dephlegmating towers similar to the types previously described. In many cases where such distillation is carried out in a continuous battery only certain stills of the series are so equipped. Where the purpose of stilling is merely to obtain color and gravity, a slow careful rerunning, with or without a small amount of top or bottom steam, according to conditions, often accomplishes the desired object without the aid of towers. In general, however, rerunning involving passage through a properly designed tower cannot fail to be of benefit, unless there are several stills in the battery distilling a previously close-run product. The common practice of using uniform towers for a variety of work naturally secures anything but efficient results. The turning over of large quantities of ends, resulting in the increase of fractional percentages of more valuable products, is a feature of refining that should be watched from a cost standpoint, apparent profits often being eaten up in fuel and depreciation costs.

If second-run distillates, after treatment with sulphuric acid and subsequent neutralization, dissolve litharge without precipitation, when agitated with sodium plumbate (doctor [1] solution), they must be specially handled, either prior to or during distillation, so that the rerun distillate will be "sweet," [2] or at least yield to standard methods of treatment.

Of the few successful methods for handling "sour" [2] distillates, that of Frasch, in which the distillate to be sweetened is distilled in a special type of still over finely ground black copper (cupric) oxide, is perhaps the best known. In the actual working of the process a so-called sweetening still [3] is employed, consisting of a closed upright, flat-bottomed, cylinder (cheesebox type) of about 1200–1500 barrels capacity, fabricated with a perfectly smooth bottom sheet, all seams being butted and reinforced through butt straps with rivets countersunk on the inside, it being absolutely essential that no rough surfaces be presented where the copper might stick and burn on. The copper is kept in suspension during all stages of the process by chain drags attached to a hexagonal pyramid spider frame attached to and driven by a vertical central shaft,

[1] See "Chemical Treatment," p. 368.

[2] The term "sweet" distillate is applied usually to overhead kerosene fractions, which upon treatment with sulphuric acid and subsequent neutralization, can be finished with "doctor" solution, the latter removing all traces of odorous sulphur compounds and leaving the finished oil unreactive to a second application, i.e., sweet. Even if steaming or free sulphur is required to throw out the lead sulphide that is formed when the doctor solution separates or "breaks" from the oil, the original distillate is still called "sweet" as long as the finished oil therefrom stands the "doctor" test ultimately without reaction. Before the addition of the acid it may be strongly reactive to lead plumbate solution, and show a percentage of 0.120 sulphur. "Sour" distillate, on the other hand, is a distillate that after treatment with sulphuric acid, neutralization, etc., still dissolves lead, and cannot be induced to "break" by the usual means of addition of free sulphur, steaming, etc. In this connection the reader should not be confused between "sweetness," i.e., reaction to "doctor," and actual sulphur content. An oil may be low in sulphur percentage and strongly reactive to the "doctor" solution, the converse being equally possible. See also "Chemical Treatment," p. 369.

[3] The setting for the above type of still is shown in Fig. 129, p. 234. Another form of sweetening still invented by Frasch allows vapors from crude to pass through two brushes of 10-gage steel wire, the brushes themselves being 5½ feet in diameter by 16 feet long, revolving in close-fitting shells, into which the needed amounts of copper oxide and heavy oil carrier are fed. To prevent condensation, the vapor is first caused to pass around the shells, then through the brushes to the condenser, the heated shells insuring a gaseous phase contact of the distillate with the slowly-revolving brushes (6 R.P.M.), which are continually immersed in the heavy oil mixture of copper oxide. The desulphurizing action of the latter on the vapor thus evolved does not appear to be as effective as when the distillate is in liquid phase and distilled from a medium in which the oxide is suspended, so that the cheesebox type of sweetening still is preferred for severe duty.

which passes out through a standard stuffing box, at the center of the top of the still. This shaft is rotated by means of a bevel gear and pinion drive, through the agency of a clutch sprocket and link belt, from a long horizontal shaft extending the entire length of the battery of stills. The primary source of power for driving the main shaft is usually installed in duplicate to guard against shutdowns.

The distillate to be sweetened is pumped to the still together with its quota of copper oxide, the latter being incorporated in a small quantity of heavy oil, rendering possible its transfer by a pump. After 80–85 per cent has been distilled off, a second charge of distillate together with additional copper oxide is pumped in on top of the hot residuum, care being taken to keep the latter in constant agitation. A small amount of distillate given off during the charging of the hot still " runs sour " and is returned to the process. Distillation and recharging are alternated until some six or seven charges of copper oxide have accumulated, when the bottoms are withdrawn still-stripped and cleaned, and made ready for a fresh cycle of operations.

The quantities of copper oxide used for successive charges, of approximately 1200 barrels each, of a typical sour Lima distillate are given below in the customary order of charging, the cuts employed on the water-white distillate following immediately afterward. It will be noted that the water-white distillate is run when the copper oxide is freest from sulphide, and the bottoms least likely to hurt the color of the distillate.

Typical Weights of Copper Oxide for Sweetening Sour Lima Distillate

(Charge; approximately 1200 barrels of sour distillate per run)

No. run	Amount of copper oxide, pounds	Grade charged	Sulphur
1	7500	Sour water-white distillate	0.32
2	6500	Sour water-white distillate	0.32
3	6500	Sour white distillate	0.32
4	5500	Sour water distillate	0.36
5	5000	Sour water distillate	0.36
6	4500	Sour water distillate	0.36

Typical Yield in Sweetening Lima Sour Water-white Distillate, 0.32 S.

(Charge 1200 barrels, 42.4.° Bé., sour water-white distillate, run dry in vertical cylindrical sweetening still to gas-oil. 24 hours running time)

Cut	Grade	Yield per cent
Over 48	Naphtha	16.5
48–40	Sweet water-white distillate	54.7
40-off	Heavy end	10.9
Bottom	Gas oil	15.4
	Stilling loss	2.5
	Total	100.0

The sweet water-white distillate produced in the above manner, running about 0.10–0.12 per cent sulphur, now readily yields to standard treating methods; but it should be noted that copper oxide employed as above has little action on the heavy ends of 37° to 39° Bé. Lima origin, which consequently must be sweetened by other means. In fact, the entire action of copper oxide seems to be governed by mass law, since it must be used in considerable excess to produce the desired effect. The copper press cake, as filter-pressed from the still residuum, contains only 15 to 17 per cent, sulphur, when reduced to an oil-free basis. To recover the copper oxide, the sweetening-still bottoms are cooled to a safe temperature and filter-pressed. The resultant press cake, containing about 14 per cent of oil is burned on a continuous traveling straightaway furnace, from which it emerges in a coarse lump form, free from oil, and partially reduced in sulphur content. It is next passed through crushing-rolls and delivered in a coarse powder to standard types of ore-roasting furnaces, in which practically all of the sulphur is removed, and cupric oxide is regenerated. The finishing step consists in grinding the oxide in impact mills to a 200-mesh product. Loss of copper during the grinding operation is prevented by a series of dust-catching devices. The flue dust volatilized during roasting settles in special chambers through which the furnace gases pass, and is later used in process. With the passing of the great bulk of the Lima and Indiana production the Frasch process has been supplanted to a great extent by simpler treating methods.

Other sweetening methods involve a series of treatments with sulphuric acid, followed by sodium plumbate (doctor solution). Finishing by rerunning is employed to a considerable extent, but as the final distillations are conducted in standard stills along well-known lines a discussion of them falls more naturally under the head of treating.[1] Lack of space also prevents the discussion of processes like the Pitt,[2] which while employed by one of the larger independent companies for a considerable period is now no longer utilized.

Considerable "cracking" took place in the older method of dry distillation, especially when the still was held for seven hours after "off natural water-white" distillate. Even now cracking occurs in tower-still practice when paraffin distillate is run off, and also when wax distillate is rerun. The term is generally held, however, in modern refining phraseology to mean the art of producing low-boiling-point hydrocarbons suitable for motor fuel, in commercial quantities, from distillates or residua of high molecular weight. Generally, though not necessarily, this is done under pressure, and as such will be found discussed at length in another chapter of this volume.[3]

However, the recovery of liquid condensates from gases produced during the incidental "cracking" that occurs in ordinary refining, as well as from incomplete condensation of natural light hydrocarbons originally present, has come to be of decided importance in many of the larger plants. The writer therefore includes a tabulation giving a rough idea of the composition and amount of such gases produced. Unless a skimming plant is operating on crude oil of extremely high gravity, either natural or charged with casing-head condensate, the amount of permanent recoverable liquid product from still gases should be negligible if the condensing equipment is efficiently designed and operated. On the other hand, where lubricants are manufactured, or where general refining is practiced, there is always a certain amount of incidental "cracking" with corresponding gas formation. This, together with the usual inadequacy of the water supply for effecting the recovery of natural light gasolines, will often justify a compression unit, or in certain cases an absorption system

[1] See p. 367.

[2] For further details of this process, which was employed at one time by the Paragon Refining Co., Toledo, Ohio, see U. S. Patents 379,492, March 13, 1888, and 411,394, September 17, 1889.

[3] See p. 427.

for recovered gas. This is best determined by an actual test of the still gases evolved by methods described in the chapter of this volume devoted to the extraction of gasoline from natural gas. The following data are taken from a series of actual plant tests conducted by the writer. Considering the recent achievements of Ellis,[1] they suggest a somewhat neglected field for chemical research, especially when the high percentage of unsaturated hydrocarbons existing in certain still gases is noted.

Production of Still Gas from Indiana Crude Oil Distilled to Coke

(Charge 1260 barrels 36.1° Bé., 57 hours running time)

Per cent by volume, quantities in cubic feet

Time	Air	H_2S	C_xH_y	Meter-age	Total gas (Air free)	Total C_xH_y gas (Air free)	Periods
7.00 p.m.	100.0	Trace	0.0	940	0	0	Fired
9.00 p.m.	100.0	Trace	0.0	960	0	0	
11.00 p.m.	100.0	Trace	0.0	880	0	0	
1.00 a.m.	97.3	0.1	2.6	900	24	23	Over
3.00 a.m.	91.1	0.2	8.7	1,600	143	139	
5.00 a.m.	97.0	0.1	2.9	1,380	41	40	Settled to boil
7.00 a.m.	98.0	Trace	2.0	1,220	24	24	
9.00 a.m.	98.0	Trace	2.0	1,200	24	24	
11.00 a.m.	97.1	Trace	2.9	1,300	38	38	Light worm 43°
1.00 p.m.	92.1	2.0	5.9	1.940	153	114	
3.00 p.m.	95.2	1.5	3.3	2,200	106	73	
5.00 p.m.	87.4	6.2	6.4	2,600	328	166	Light worm 41°
7.00 p.m.	80.3	9.5	10.2	3,440	676	350	
9.00 p.m.	87.2	4.3	8.5	3,340	428	284	
11.00 p.m.	87.7	4.8	7.5	3,380	415	254	
1.00 a.m.	85.4	7.2	7.4	3,400	496	254	Heavy worm paraffin distillate
3.00 a.m.	65.7	14.0	20.3	4,260	1,460	865	Light worm 45°
5.00 a.m.	50.2	18.0	31.8	4,580	2,280	1,460	
7.00 a.m.	37.1	26.4	36.5	4,940	3,140	1,800	
9.00 a.m.	20.1	29.4	50.5	5,080	4,070	2,583	
11.00 a.m.	13.2	24.2	62.6	5,440	4,720	3,410	
1.00 p.m.	8.8	17.4	73.8	4,600	4,180	3,400	Light worm 48°
3.00 p.m.	8.6	5.6	75.8	3,800	3,100	2,880	
5.00 p.m.	7.2	3.8	89.0	4,800	4,450	4,270	
7.00 p.m.	3.2	3.0	93.8	5,000	4,840	4,700	
9.00 p.m.	2.0	2.0	96.0	5,200	5,100	5,000	
11.00 p.m.	2.0	1.8	96.2	4,800	4,710	4,620	
1.00 a.m.	2.5	1.0	96.5	4,200	4,090	4,055	
3.00 a.m.	0.5	7.0	92.5	4,780	4,760	4,430	
5.00 a.m.	1.5	6.0	92.5	3,640	3,580	3,576	
Total quantities.....	....	....	....	95,800	57,376	48,832	

[1] See Petrol-Alcohol, p. 399, this volume.

Approximate Analyses of Waste Still Gases

(Samples taken from mains, air content due to open vents, stills not running, etc.)

Composition of gas	Tower stills (Indiana crude) per cent	Steam stills (Illinois crude) per cent	Tar stills (Kansas crude) per cent
Hydrogen sulphide	8.0	4.1	2.2
Oxygen	5.0	3.1	1.2
Nitrogen	19.0	11.8	4.6
Unsaturated hydrocarbons	10.8	0.0	18.4
Saturated hydrocarbons	57.2	81.0	73.6
Totals	100.0	100.0	100.0

In the above tests no attempt was made to determine the amount of unsaturated hydrocarbons present, but if the percentage previously given for average tower-still gas (15.9 per cent) is applied, the unsaturated hydrocarbon content would be 7764 cubic feet. In certain plants, after condensable light naphthas have been removed the still gas is further purified and used as a source of power for gas engines or as fuel for soldering in can plants, or sold for domestic purposes; in other plants it is burned directly under stills or boilers.

While the products of dry-heat distillation are in the main intermediates, requiring subsequent refining before marketing, a brief description of their characteristics may not be out of place at this point.

Products Obtained from Crude Stills

Gasoline.—This product when it is possible to obtain it by direct distillation from crude, generally runs about 21 to 25 in color, 95° to 120° F., initial boiling point, 350° to 400° F., end-point, and 64 to 66° Bé. gravity. A lower gravity than 64° is rarely obtained because the stream, even from a low-sulphur crude, fails to stand "doctor" test in the portion from 66° to 60° Bé. gravity down, depending on the nature of the crude, the rapidity of distillation, etc. It is obvious that this grade of gasoline can be made only from comparatively few crudes; it is used principally for blending, with treated or steam-run gasolines of higher end-point and lower gravity.

Benzine-naphtha tops.[1]—These intermediates, usually the first products obtained in dry distillation,[2] range from water-white to standard white in color, 400° to 500° F.

[1] The trade usually understands benzine to be an unrefined gasoline and naphtha, and the latter products to be steam-distilled, deodorized, or otherwise highly refined. But no such line of demarcation exists in refining parlance. Here the term naphtha is applied to the light, sweet, high-gravity product of 67°–69° Bé. gravity obtained from Pennsylvania crude, known as "P. C." naphtha. It is also applied to the grade first over from Ohio crude known as "sour" naphtha; to the light gaseous product steam-stilled from "cracked" distillate, termed "gas" naphtha; and lastly to the sweet steam-refined, deodorized, colorless product, somewhat heavier than gasoline, obtained at the cut of 67°–53° Bé. following P. C. naphtha on Pennsylvania crude. With the migration of many Pennsylvania refiners to the West, the term "benzine" became somewhat generally applied to all first-over products from crude not suitable for direct sale as gasoline, so that the names benzine and naphtha are without significance among refiners unless detailed specifications are given. The term "tops" is distinctly limited to Californian and Mexican crude refining practice. It includes all gasoline stock discharged from the evaporator column where subsequent dephlegmation is not immediately practiced.

[2] Under dry distillation are considered such stilling methods as involve only a minimum quantity of steam directly introduced for agitation purposes or formed from water originally present in the crude.

end-point, and anywhere from 66° to 48° Bé. gravity, depending on the nature of the crude cuts employed, etc. These products are generally reactive to "doctor" and require additional refining before marketing.

Light end, engine distillate.—Following the naphtha or tops cut, a light-gravity distillate of the same general characteristics as the naphtha itself, but usually of 50° to 46° Bé. gravity, is sometimes set aside for subsequent rerunning into special solvents having a specified flash. In California practice this is marketed directly as engine distillate; number 1 is 50° Bé. gravity; number 2 is 45° Bé. gravity.

Kerosene distillate, kerosene stock.—This product follows the light end or engine distillate, and varies in color, reaction to "doctor," burning quality, flash, etc., according to the nature of the crude. For direct sale, or finishing by simple treatment, it usually runs from 41° to 46° Bé gravity, 150° to 175° F. burning-point [1] but where cut for sweetening, rerunning, fuming acid treatment, etc., it stands 40° to 44° Bé. gravity, and varies widely in flash and burning test.

Inspection of Burning Oil Distillates

Date	Source	Grade, water-white	Gravity, degrees Bé.	Flash, degrees F.	Initial boiling point	Over At 300	300 350	350 400	400 450	450 500	500 550	Above 550
1907	Penn...	120°	47.2	105–120	220	12.6	21.6	13.3	6.5	5.0	10.9	30.1
1907	Penn...	150°	48.2	122–150	305	0.0	10.0	23.0	21.0	17.5	12.5	16.0
1912	Ohio...	150°	46.2	124–150	310	0.0	7.0	28.0	27.5	22.0	10.0	5.5
1915	Okla...	42°–44°	42.2	124–150	320	0.0	7.0	20.1	22.8	23.5	14.6	12.0
1921	Kans...	41°–43°	41.5	150–175	345	0.0	0.0	20.0	39.0	29.0	9.7	2.3

Heavy end, power distillate, petroleum distillate.—This grade is cut from Eastern and Mid-Continent crudes between the kerosene distillate and gas-oil. It is usually set aside for rerunning for prime-white or standard-white distillate, although it is often sold directly under a variety of names for light-horse-power engine fuel. Like the cut immediately preceding, "heavy end" varies in color, flash, sulphur content etc., with the nature of the crude employed. It is usually of a light straw-color, 150° to 200° F. flash and of 37° to 40° Bé. gravity.

Gas-oil.—Intermediate between "heavy end" and paraffin distillate, light gas-oil is produced. This is distinguished from heavy gas-oil, obtained in the subsequent reduction of paraffin distillate. As cut from crude, gas-oil usually runs 33° to 37° Bé. gravity, 175° F. flash or better, is of a straw-color, and varies in cold test from 30° to 10° F., depending on the nature of the crude, and the cuts employed. It finds direct sale as an absorbent or scrubbing oil, and when mixed with heavier gas-oils, forms the 32° to 36° Bé. gas-oil of the trade. It is also sold for special fuel, and may be further refined into grease stock or light, non-viscous lubricants.

[1] With the exception of sour distillates cut for rerunning, and aromatic (California) water-white stock, requiring fuming acid treatment, it has been the practice for many years to cut natural water-white distillate at test, i.e., within the legal requirements for intended point of shipment. Prime-white and standard-white oils were formerly made by steaming a mixture of light and heavy ends to the required flash and in this way retaining a considerable portion of what would now form gasoline batching stock. The small demand for gasoline in the early days of the industry, the necessity of light ends for balancing heavy fractions, reducing viscosity within wick-climbing limits, and supplying the foreign and domestic demand for burning oil, had much to do with the low flash and fire test of early burning oils, as well as resulting in the then needed, though at present, archaic, inspection laws. Under present refining methods, light ends are retained in benzine stock, heavy ends are either dephlegmated into low viscosity wick-climbing products, or retained in the gas oil. In general, a better, more uniform, free-burning kerosene is produced to-day at 41°–43° Bé. gravity, than the early oils of higher figure, even though the present grades will frequently test 175° burning point or higher.

Stove distillate.—This product is not to be confounded with naphtha stove distillate. It is of 30° to 34° Bé. gravity, and is obtained from California crude. It corresponds in point of cut to the gas-oil of the Eastern or Mid-Continent crudes, but on account of the asphaltic nature of the base it is much darker in color.

Fuel oil.—This grade is produced in enormous quantities by continuous skimming plants in the Southwest, and by topping plants on the Pacific Coast. It varies from 26° to 14° Bé. gravity, with corresponding fluctuations in its other physical constants. These depend on the nature of the crude, the extent of gas-oil, or stove distillate stripped, the amount of bottom steam used, etc. Its color ranges from dark green to black, and its cold test from 80° to 10° F. It is commonly marketed in the Mid-Continent field on guaranteed gravity alone, such as 26° to 28°, 24° to 26°, and 22° to 24° Bé. fuel oil. Compliance with the United States fuel oil specifications and with the British Admiralty requirements, are also guaranteed by many refiners. The specifications for California and Mexican fuel are somewhat broader, this heavy fuel being used in enormous quantities by the western railroads, Pacific Coast steamship lines, and artificial gas plants.[1]

Fuel oil (Navy Standard), is specified in the report of the Committee on Standardization of Petroleum Specifications, Bulletin No. 5, effective December 29, 1920, as follows:

General statement.—This specification covers the grade of oil used by the United States Government and its agencies where a high-grade fuel oil is required.

Fuel oil shall be a hydrocarbon oil, free from grit, acid, and fibrous or other foreign matters likely to clog or injure the burners or valves. If required, it shall be strained by being drawn through filters of wire gauze of 16 meshes to the inch. The clearance through the strainer shall be at least twice the area of the suction pipe, and the strainers shall be in duplicate.

Properties and tests. Flash point.—The flash point shall not be lower than 150° F. (Pensky-Martens closed tester). In case of oils having viscosity greater than 30 seconds at 150° F. (Saybolt Furol viscosimeter) (8° Engler) the flash point shall not be below the temperature at which the oil has a viscosity of 30 seconds.

Viscosity.—The viscosity shall not be greater than 140 seconds at 70° F. (Saybolt Furol viscosimeter) (40° Engler).

Sulphur.—Sulphur shall not be over 1.5 per cent.

Water and sediment.—Water and sediment combined shall not amount to over 1.0 per cent.

All tests shall be made according to the methods of testing fuel oils adopted by the Committee on Standardization of Petroleum Specifications.

Old British Admiralty specifications. Quality.—The oil fuel supplied under this contract shall consist of liquid hydrocarbons and may be either:

(*a*) Shale oil; or
(*b*) Petroleum as may be required; or
(*c*) A distillate or a residual product of petroleum;

and shall comply with the Admiralty requirements as regards flash point, fluidity at low temperatures, percentage of sulphur, presence of water, acidity, and freedom from impurities.

The flash point shall not be lower than 200° F. closed test (Abel or Pensky-Martens).

The proportion of sulphur contained in the oil shall not exceed 0.75 per cent.

[1] For detailed information regarding the commercial consumption of fuel oil, its economics, etc., see Bull. 69, Cal. State Min. Bur., 1914, 83; Report 291 (1, 285 et seq.) of the Mines Branch, Canadian Dept. of Mines; Jones, J., Electricity, Power and Gas, 24, 492; Wadsworth, Efficiency in the Use of Oil Fuel, Bureau of Mines, 1919; Stillman, Trans. Am. Soc. Mech. Eng., 33 (1911), 887.

The oil fuel supplied shall be as free as possible from acid, and in any case the quantity of acid must not exceed 0.05 per cent, calculated as oleic acid, when tested, by shaking up the oil with distilled water, and determining by titration with decinormal alkali the amount of acid extracted by the water, methyl orange being used as indicator.

The quantity of water delivered with the oil shall not exceed 0.05 per cent.

The viscosity of the oil supplied shall not exceed 1000 seconds for an overflow of 50 cubic centimeters at a temperature of 32° F. as determined by Sir Boverton Redwood's standard viscosimeter (Admiralty type for testing oil fuel).

The oil supplied shall be free from earthy, carbonaceous or fibrous matter, or other impurities which are likely to choke the burners.

The oil shall, if required by the inspecting officer, be strained by being pumped on discharge from the tanks, or tank steamer, through filters of wire gauze having 16 meshes to the inch.

The quality and kind of oil supplied shall be fully described. The original source from which the oil has been obtained shall be stated in detail, as well as the treatment to which it has been subjected, and the place at which it has been treated.

The ratio which the oil supplied bears to the original crude oil should also be stated as a percentage.

Common specifications for California fuel oil: (1) Viscosity must be such that oil will flow freely through a 4-inch pipe at 70° F., (2) Water content must be less than 2 per cent, using gasoline in the testing centrifuge; (3) Flash shall not be less than 110° F. open cup; (4) Fuel shall be sold on a 63° F. basis with 1 per cent correction for every 25° F.; (5) Gravity shall be between 14° and 29° Bé. See also Bunker fuel Oil "A," "B," "C," Report of the Committee on Standardization of Petroleum Specifications, Bulletin No. 5, effective December 29, 1920. Also British Mission Requirements.

Fuel oil varies from 17,500 as a minimum to 20,000 B.t.u. as a maximum, the average values ranging from 18,500 to 19,500 B.t.u. per pound. The calorific value of the fuel oil may be determined with accuracy only in some form of bomb calorimeter, and, where absolute precision is not required, by the formula of Dulong. This is given for coal on page 810. Formulæ for calculating fuel values may also be consulted in Thorpe's Dictionary of Applied Chemistry, 1912, **2**, 605, and Gebhardt's "Steam Power Plant Engineering," 4th edition, page 34, also Carpenter and Diederichs' "Experimental Engineering," 7th edition, page 510. The variations in the fuel values of different fuel oils is by no means so great as for coals because of the variation in coals.

The figures on the following page taken from the Babcock and Wilcox Co.'s handbook on steam, and from other authorities, give an idea of the variation existing in the calorific value of various petroleum products.

Tar.—Closely allied to fuel oil is the substance tar. It represents a strictly dry-run product—the intermediate from which paraffin distillate was distilled before the general adoption of tower stills. As no steam was used, the tar varied considerably in composition, according to the extent of cracking practiced. When first taken from the stills it contained a considerable quantity of suspended carbon and fine coke. It usually showed on test 22° to 24° Bé. gravity, 340° to 350° F. flash, and 400° to 410° F. burning test; it found a limited sale for fuel.

Paraffin distillate.—This intermediate, the base for paraffin wax and paraffin oils, should be distinguished from wax distillate produced by steam reduction of fuel oil, the former being a crystalline product ready for pressing, the latter a semi-amorphous substance requiring additional rerunning. As produced at tower or tar stills, paraffin

distillate is of 27° to 30° Bé. gravity, 140° to 200° F. flash, 200° to 260° F. burning test, 60 to 80 viscosity at 100° F., 65° to 75° F. cold test, and of a deep yellow color. Inspection of this product varies considerably according to the type of tower stills, the cuts employed and the amount of cracking practiced. The objective in distillation is to secure a product of high viscosity and flash, that at the same time will press readily without gumming, in other words to maintain yield and quality in both slack wax and pressed distillate.

Smudge oil.—Corresponding to the paraffin distillate cut on Eastern crudes, a dark distillate of 26° to 28° Bé. gravity is cut from California crude. It is sold as a smudge oil for use in the citrus belt to prevent damage to trees from frost.

Wax tailings.—See note 5, page 329.

Coke.—See note 6, page 330.

Composition and Calorific Value of Various Petroleum Products

Grade	Carbon, Per cent	Hydrogen, Per cent	Sulphur, Per cent	Oxygen, Per cent	Gravity, Degrees Bé.	B.t.u.	Authority
Galicium crude	82.2	12.1	5.7	....	31.1	18,416	Babcock and Wilcox
Borneo crude	95.7	11.0	....	3.31	....	19,240	Orde
Calif. kern crude	85.6	11.89	1.09	1.42	16.0	18,840	Babcock and Wilcox
Java crude	87.1	12.0	....	0.9	21.8	21,163	Babcock and Wilcox
Kansas crude	....	....	0.32	....	33.1	18,735	Smith
Indiana lubricating distillate	....	....	....	....	27.3	19,382	Robinson
Ohio crude	83.7	14.4	0.60	1.3	36.0	18,815	Smith
Ohio fuel oil	....	....	....	....	24.5	19,759	Robinson
Pennsylvania crude	85.0	13.6	0.07	1.33	44.7	18,900	Smith
Penn., 150° water-white oil	....	....	....	....	46.3	20,000	Robinson
Mexican crude	....	....	....	....	22.1	18,840	Babcock and Wilcox
Russian Baku crude	86.7	12.9	....	....	28.6	20,691	Booth
Texas crude	84.6	10.9	1.63	2.87	21.6	19,060	U. S. Naval Board
Texas reduced crude	....	....	....	....	20.4	19,351	Robinson
Texas gas oil	....	....	....	....	27.5	19,612	Robinson

The results of inspection of various yields of fuel oil from a typical Oklahoma skimming plant are tabulated below:

Inspection of Fuel Oil from an Oklahoma Skimming Plant, Distilling 38.1° Bé. Cushing Crude

Yield, per cent	Degrees Bé.	Flash test	Fire test	Viscosity/130	Cold test, Degees F.
52	29.6	200	245	55	30
48	27.6	255	300	95	33
44	26.1	290	355	124	36
40	24.9	320	385	163	38
35	22.3	350	410	210	40

II. Distillation by Steam

The use of steam as an aid in the distillation of petroleum products was early practiced,[1] it having been discovered that where steam was used, the overheating of the contents of the still was prevented, sweeter products were obtained, and distillation in general proceeded more smoothly. Moreover, the partial pressure of the hydrocarbon content of a mixture of oil and steam vapor is less than the atmospheric pressure, and according to the well-known law of partial pressures, allows the hydrocarbons to distill at temperatures considerably below their boiling points,[2] thus aiding in separation and preventing decomposition. Thus steam was found particularly advantageous in separating the more volatile naphthas from burning-oil distillates, its use being largely responsible for the progress made in the development of maximum burning-oil yield from crude, which reached its height in about 1912.

While as early as 1860,[3] a crude form of dephlegmating device had been suggested, it was not until a simplified form of the Coffey alcohol still tower was adapted to the industry, that really efficient separation took place. Such towers acted as combined dephlegmators and heat exchangers. As recently as 1907 there was little demand for gasoline under 70° Bé. gravity; therefore the function of the steam still at that period was largely confined to bringing a mixture of light and heavy ends to test, although a 70° Bé. gravity gasoline with 3 per cent of residue at 300° F. was beginning to be made in quantity. Continuous distillation was practiced then in much the same way as it is to-day. Two stills in a battery usually sufficed, however, to secure the requisite test on the distillate. The bulk of the naphtha was removed in the first still, and the operation was completed in the second unit, to which the contents of the first still flowed by gravity upon rising above a certain level. The heavy test naphtha, or light end dropped out from the bottom of the one tower which commonly supplied the two stills. It also flowed to the second or test still, and helped to maintain the desired gravity and quality of the finished distillate. "Untest" stock was continuously charged to the top of the tower, and test distillate was pumped away from the second still in like manner. The process required only occasional adjustment of pumps and checking of the fire test, 8000 to 9000 barrels of distillate usually being handled in twenty-four hours by two 1800-barrel stills. The stripping yielded 3 to 4 per cent of naphtha. Heat exchanging was also practiced, and both high-pressure (60 pounds), and low-pressure (8 to 12 pounds) exhaust steam were used, so that the art of steam-stilling at the period mentioned could be said to have been efficiently conducted. In short, with the exception of recent installations including the regulation furnace setting, and the adoption of special tower packing,[1] in place of the stone or brick of earlier days, there has been little change in general steam-stilling equipment and process for the past fifteen or twenty years. Not a few plants, in other respects modern, continue to employ the even older cheesebox type of steam still, generally imperfectly insulated, unprovided with dry coil or furnace setting, and necessarily requiring excessive steam consumption for the volatilization of the heavy naphthas which now form an important constituent of ordinary gasoline.

A battery of modern steam stills is illustrated in Fig 151, page 344. Fig. 152, page 344, shows a different design. In some refineries it is the practice to use a separate steam still for each cut of benzine at crude stills, pumping in continuously at the top of the tower. The speed of the pump is regulated by a constant gravity stream,

[1] Joshua Merrill, of the Downer Kerosene Company, Boston, Mass., is credited with being the first to suggest the introduction of steam into petroleum during its distillation.

[2] For scientific discussion on the physical laws involved in steam distillation of hydrocarbon products, see Gurwitsch, Wissenschaftliche Grundlagen der Erdolbearbeitung, 117 (1913).

[3] See U. S. Patent 28,246, May 15, 1860.

until 60 per cent of bottoms has accumulated, or until the end-point of the gasoline becomes affected, when the charge is withdrawn, and the still is filled anew with fresh benzine or naphtha. This semi-continuous method of operation usually allows a steam still to be run for from seven to ten days before pumping out. It permits the different benzine cuts to be separately treated by methods best suited to their individual

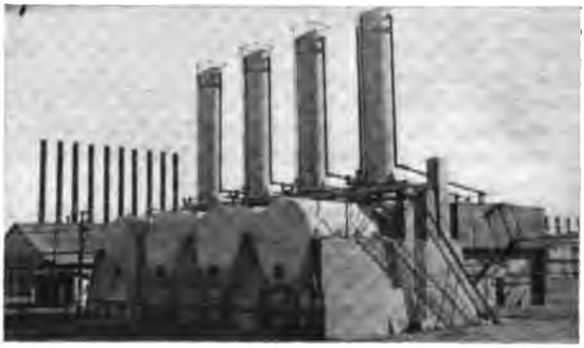


FIG. 151.—A battery of steam stills.

characteristics, but involves the turning over of an unnecessarily large bulk of charge prior to pumping out the bottoms. A modification in method is to pump out a portion of the charge intermittently while the entering stream is either reduced in volume or stopped for the time being. In compartment steam stills continuous charging and simultaneous pumping out of the bottoms is practiced with more or less success.

FIG. 152.—Double steam-still unit.

Other plants batch their benzine at crude stills, and fractionate into constant gravity streams at steam stills. The degree of separation depends upon the number of stills connected in a battery, four being the commonly accepted number. This method, under careful watching of steam pressure and fire, insures uniform gravities and constant operation; but with many crudes it is more difficult to maintain streams which are sweet to the "doctor" test from the third and fourth stills of the battery than by the semi-continuous method of operation. Each system, therefore, has its advocates.

Eastern and Mid-Continent practice generally favors the externally fired steam still for refining the heavier naphtha fractions, while Pacific Coast usage gives preference to the dry-coil still, in which the temperature of the still contents is maintained at the desired point, by a series of tight steam coils, rather than by a free fire beneath the still. This method certainly recommends itself by its ease of control and safety of operation. Considering the higher efficiency of the steam boiler over the usual still setting, it is probably, in many instances, actually more economical in ultimate fuel consumption than the apparently more direct means of heat transfer. Where a counter-current continuous system is employed the advantage is more pronounced.

Steam-stilling of crude is also practiced in several refineries and at certain centers where crude is gathered before its receipt by the pipe-line. In the first instance, the process is sometimes used to prevent contamination of the water-white color of the first-over product by gas-oil or wax distillate left in the worm from the run immediately preceding. This system is carried out in several Pennsylvania refineries where the remainder of the stilling is a batch process. About 60 per cent of the gasoline-benzine content is removed in a continuously operated tower or "hog" still. The overhead product is condensed according to the usual standard methods. The reduced crude flows into a separating still maintained at a temperature sufficient to allow complete separation of the water entrained during reduction. Aside from the fact that it obviates the necessity of rerunning the valuable, highly volatile, contaminated gasoline, this process produces a cleaner steam-refined stock for subsequent filtration, or direct sale. In other cases steam-stilling of crude is conducted principally to wash out accompanying salt water, and to prevent the deposit of salt in subsequent coking. The life of the still bottoms is thereby lengthened considerably, and an electrolyte-free coke is produced. Steam-stilling at gathering points is practiced to supply local markets with gasoline, to relieve congestion of pipe-lines, and occasionally to render certain tariffs inoperative. A combination of steam and vacuum process, i.e., the Ernest Scott System, is employed in the stripping of crude in the Lobitos district of Peru.

In view of the widely varying range of gasolines offered for sale as motor fuel, the special-test solvent naphthas,[1] turpentine substitutes,[2] aromatics from the Pacific coast crude and the blended products of casing-head and absorption gasolines,[3] benzol and other by-product mixtures, it would be a hopeless task to include the specifications of even a small fraction of these products, or to specify the cuts employed in their preparation. Inasmuch as the majority of the above-enumerated hydrocarbon mixtures are sold on end-point or distillation range, it suffices to state that products of similar boiling-point range obtained from different crudes are cut at widely different gravities, and conversely, distillates or blends of similar gravity produced from different localities vary correspondingly widely in general distillation range. In short, the preparation of naphtha derivatives is an individual problem of each refiner, and is influenced by the crude employed, the object desired, and the legal restrictions attending the sale of the final product as prepared for the market.

[1] The constants of solvent naphtha, or varnish maker's and painter's naphtha, usually range from 85°–105° Abel test, 275°–300° initial boiling point, and from 400°–440° F. end-point. The gravity varies widely with the nature of the crude employed.

[2] Turpentine substitutes are of the same general nature as the above, but are frequently mixed with small percentages of pure spirits of turpentine, or a proprietary product to simulate the odor of turpentine.

[3] See page 729 this volume, also Technical Paper 10, Bureau of Mines (1912); Bull. 120, Petroleum Technology 23, Bur. Mines; Bull. 151, Petroleum Technology 40, Bur. Mines (1918); Bull. 176, Petroleum Technology 50, Bur. Mines (1919), for information regarding the manufacture of casing-head and absorption gasoline. For inspection of blends marketed in the United States in 1919, consult Bull. 191, Petroleum Technology 59, Bureau of Mines (1920).

For a systematic survey of the quality of gasoline marketed in the United States for the past five years, consult Technical Paper 163, Petroleum Technology 38, Bureau of Mines (1916); Bull. 191, Petroleum Technology 59, Bureau of Mines (1920). The tables immediately following are selected from the last-named reference.

Data on the Refinery Production of Gasoline in the United States for a Period of Fifteen Years, 1904 to 1918, inclusive

(The unit barrel is 42 U. S. gallons)

Year	Crude run to refineries, barrels	Production of gasoline, barrels	Yield of Gasoline	
			Per cent	Gallons of gasoline per barrel of crude run
1904	66,982,862	6,920,000	10.3	4.3
1909	120,775,439	12,900,000	10.7	4.5
1914	191,262,724	34,915,000	18.3	7.7
1916	246,992,015	49,020,967	19.8	8.3
1917	315,131,681	67,870,153	21.6	9.1
1918	326,024,630	85,007,451	26.1	11.0

Gravities of Average Motor Gasoline Produced from Typical Crudes

Type of crude	Gravity of Gasoline	
	Degrees Baumé	Specific gravity
Pennsylvania	60.5 to 64.4	0.735 to 0.720
Mid-Continent	56.9 to 61.3	0.749 to 0.732
California	56.4 to 59.4	0.751 to 0.739

The gravities of the samples included in the series range from 48.3° Bé. (specific gravity, 0.785), for an engine distillate from California, to 74.7° Bé. (specific gravity, 0.684), for a blend of casing-head gasoline with refinery gasoline from Pennsylvania. Gravities of the average grades of motor gasoline produced from different typical crudes were approximately as given above.

Changes in · olatility in different sections of the country.—The table following shows the average distillation figures for all the samples collected in each of the twenty states covered by both the 1917 and 1919 surveys. In one state, Ohio, practically no change is noted. This does not prove that the general grade of gasoline sold in that state has remained unchanged, because the proportion of high-test products sampled in 1919 was greater than in 1917. However, the general change in volatility was perhaps relatively less in Ohio than in many of the other states. Also, relatively small changes were shown for Louisiana, Illinois, Texas and Kentucky.

Comparison of Volatilities of Gasolines Marketed in 1917 and 1919

State	Year	Average Distillation *				
		Initial boiling-point	20 per cent mark	50 per cent mark	90 per cent mark	Dry point
Alabama	1917	117	205	252	336	399
		47	96	122	169	204
Alabama	1919	129	212	266	365	424
		54	100	130	185	218
Arkansas	1917	104	203	257	347	428
		40	95	125	175	220
Arkansas	1919	127	207	271	372	428
		53	97	133	189	220
California	1917	108	187	225	298	352
		42	86	107	148	178
California	1919	133	205	244	329	392
		56	96	118	165	200
Colorado	1917	122	199	253	360	417
		50	93	123	182	214
Colorado	1919	126	207	271	381	435
		52	97	133	194	224
Illinois	1917	113	201	262	356	414
		45	94	128	180	212
Illinois	1919	120	199	264	374	433
		49	93	129	190	222
Kentucky	1917	108	212	271	369	432
		42	100	133	187	222
Kentucky	1919	120	203	271	388	444
		49	95	133	198	229
Louisiana	1917	120	212	264	352	412
		49	100	129	178	211
Louisiana	1919	126	216	270	369	426
		52	102	132	187	219
Maine	1917	124	201	250	324	372
		51	94	121	162	189
Maine	1919	126	207	262	360	410
		52	97	128	182	210
Maryland	1917	140	217	264	338	381
		60	103	129	170	194
Maryland	1919	142	210	259	370	433
		61	99	126	188	223
Massachusetts	1917	124	205	252	331	381
		51	96	122	166	194
Massachusetts	1919	127	205	257	368	412
		53	96	125	181	211
Michigan	1917	129	214	255	347	415
		54	101	124	175	213
Michigan	1919	117	201	268	378	435
		47	94	131	192	224

* For each distillation the upper line shows temperatures in Fahrenheit degrees, and the lower line temperatures in degrees Centigrade.

Comparison of Volatilities of Gasoline Marketed in 1917 and 1919—Continued

State	Year	Average Distillation				
		Initial boiling-point	20 per cent mark	50 per cent mark	90 per cent mark	Dry point
Missouri	1917	126	203	250	345	408
		52	95	121	174	209
Missouri	1919	131	207	266	376	432
		55	97	130	191	222
Montana	1917	124	198	246	342	401
		51	92	119	172	205
Montana	1919	133	212	273	396	453
		56	100	134	202	234
New York	1917	126	201	243	325	385
		52	94	117	163	196
New York	1919	131	205	255	358	415
		55	96	124	181	213
Ohio	1917	126	203	253	345	405
		52	95	123	174	207
Ohio	1919	120	196	250	351	414
		49	91	121	177	212
Oklahoma	1917	124	196	234	311	369
		51	91	112	155	187
Oklahoma	1919	131	210	266	370	424
		55	99	130	188	218
Pennsylvania	1917	109	178	230	327	385
		43	81	110	164	196
Pennsylvania	1919	113	190	252	358	408
		45	88	122	181	209
Tennessee	1917	120	205	250	347	412
		49	96	121	175	211
Tennessee	1919	126	208	270	378	433
		52	98	132	192	223
Texas	1917	126	207	252	338	399
		52	97	122	170	204
Texas	1919	127	203	253	358	417
		53	95	123	181	214
Utah	1917	127	199	239	315	367
		53	93	115	157	186
Utah	1919	113	207	279	406	442
		45	97	137	208	228
		Average of All Samples				
Twenty states	1917	122	201	248	334	394
		50	94	120	168	201
Twenty states	1919	126	203	261	361	423
		52	95	127	183	217

Changes in volatility of products marketed by different companies.—The table on page 350 shows the average distillation ranges of the two series of samples collected from fourteen of the large marketing companies in 1917 and 1919. Evidently the refining practice of some of the companies, as regards volatility, had changed decidedly during the two-year period, whereas that of other companies had not changed much. The greatest difference is observed in the products of company 17, where the average 90 per cent point was 34° C. (61° F.) higher in 1919 than in 1917, and the average boiling point (defined in a previous connection) was 16° C. (29° F.) higher. Other companies whose products show an appreciable lowering in volatility (elevation of the boiling-range) during the two-year period are companies 6, 10, and 15.

Changes in gravity.—There was a notable tendency toward the lowering of the Baumé gravity of products during the two-year period. This was due partly to the increased use of benzol and other coal-tar distillates, but more to the decrease in volatility (increase in boiling range). The following table shows general changes in gravity for gasolines produced from typical crudes during the two-year period.

Changes in Gravity of Gasolines Produced from Three Typical Crudes

Type of crude	Gravity in 1917		Gravity in 1919	
	Degrees Baumé	Specific gravity	Degrees Baumé	Specific gravity
California	56.4 to 59.4	0.751 to 0.739	53 to 55	0.765 to 0.757
Mid-Continent	57 to 61	0.749 to 0.733	55 to 58	0.757 to 0.745
Pennsylvania	61 to 64	0.733 to 0.722	59 to 63	0.741 to 0.725

The Baumé gravity was, therefore, lowered by an average of 2 to 3° between 1917 and 1919.

The table on page 352[1] substantiates the statement made above, in regard to varying gravity for the same boiling range, etc.

The various state restrictions and requirements for quality of gasoline vary widely from the absurd to the unnecessarily severe, and cause great annoyance to the refiner, who if he wishes to do business in certain localities, must upset his routine to meet certain specifications. In the majority of cases these specifications do not necessarily mean a better gasoline. For further details the reader is referred to the chapter on testing methods, and to Dr. G. W. Gray's report; Nat. Pet. News, Vol. 21, Feb. 26, 1919 pp. 11–13.

Steam is not only employed in the rectification of naphtha and benzine, but is also largely used in the manufacture of neutral oils, asphalt fluxes, and steam-refined stocks, such refining processes being variously designated as steam-refining, steam-reducing, or, quite frequently, simply reducing. Steam reduction is practiced by practically all Eastern refiners, and by many of the plants in the Middle West, Southwest, Gulf and Pacific Coast districts. While even in the so-called dry-heat distillation process, a small quantity [2] of steam is quite commonly used, as before intimated, no actual steam-reducing can be properly said to take place until all of the kerosene distillate and at least

[1] Bull. 191, Bureau of Mines.

[2] In this treatise a small quantity of steam means 5 pounds or less per gallon of distillate produced, such runs being classed as dry-heat distillations.

Comparison of the Average Distillations of Samples Collected from Fourteen Large Marketing Companies in 1917 and 1919

Company No.	Year	Initial boiling point	10 per cent mark	20 per cent mark	30 per cent mark	40 per cent mark	50 per cent mark	60 per cent mark	70 per cent mark	80 per cent mark	90 per cent mark	95 per cent mark	Dry point	Average boiling point
1	1917	122	180	207	226	243	266	277	295	318	351	396	408	262
		50	82	97	108	117	130	136	146	159	177	202	209	128
	1919	120	180	205	225	243	262	282	304	327	361	399	417	266
		49	82	96	107	117	128	139	151	164	183	204	214	130
2	1917	120	180	201	217	232	244	261	279	300	333	365	397	252
		49	82	94	103	111	118	127	137	149	167	185	203	122
	1919	117	163	189	210	228	246	266	289	316	360	403	421	257
		47	73	87	99	109	119	130	143	158	182	206	216	125
3	1917	104	176	214	241	262	279	302	320	343	378	406	430	277
		40	80	101	116	128	137	150	160	173	192	208	221	136
	1919	108	163	198	230	257	286	311	338	367	408	439	446	282
		42	73	92	110	125	141	155	170	186	209	226	230	139
4	1917	138	189	207	223	235	250	266	282	306	338	367	397	257
		59	87	97	106	113	121	130	139	152	170	186	203	125
	1919	129	187	208	228	246	266	286	307	331	369	406	428	271
		54	86	98	109	119	130	141	153	166	187	208	220	133
5	1917	124	176	201	217	234	248	262	280	298	324	351	372	248
		51	80	94	103	112	120	128	138	148	162	177	189	120
	1919	133	190	214	232	248	264	280	298	320	354	390	412	268
		56	88	101	111	120	129	138	148	160	179	199	211	131
6	1917	117	180	207	230	244	262	279	298	322	356	390	419	264
		47	82	97	110	118	128	137	148	161	180	199	215	129
	1919	122	176	205	226	248	270	293	318	351	397	442	459	280
		50	80	96	108	120	132	145	159	177	203	228	237	138

8	1917	124	176	198	214	232	246	262	282	307	340	372	396	252
		51	80	92	101	111	119	128	139	153	171	189	202	122
	1919	138	189	210	226	243	259	277	295	316	349	383	412	264
		59	87	99	108	117	126	136	146	158	176	195	211	129
9	1917	126	181	201	216	230	244	259	280	302	340	376	412	253
		52	83	94	102	110	118	126	138	150	171	191	211	123
	1919	138	189	208	226	243	259	279	300	324	363	403	428	268
		59	87	98	108	117	126	137	149	162	184	206	220	131
10	1917	122	178	199	219	234	248	266	286	307	342	374	394	253
		50	81	93	104	112	120	130	141	153	172	190	201	123
	1919	122	176	205	230	250	273	298	322	354	394	426	446	280
		50	80	96	110	121	134	148	162	179	201	219	230	138
12	1917	115	178	205	225	241	257	273	295	318	354	390	419	261
		46	81	96	107	116	125	134	146	159	179	199	215	127
	1919	127	189	217	248	257	273	291	311	334	369	403	426	275
		53	87	103	120	125	134	144	155	168	187	206	219	135
13	1917	133	181	198	208	219	230	239	253	270	297	324	352	232
		56	83	92	98	104	110	115	123	132	147	162	178	111
	1919	131	187	203	217	230	243	255	270	288	318	349	376	246
		55	86	95	103	110	117	124	132	142	159	176	191	119
15	1917	118	180	203	219	234	248	261	280	302	327	358	390	250
		48	82	95	104	112	120	127	138	150	164	181	199	121
	1919	115	172	205	234	257	277	297	316	340	379	399	421	275
		46	78	96	112	125	136	147	158	171	193	204	216	135
17	1917	129	198	223	228	239	252	259	280	289	318	338	363	252
		54	92	106	109	115	122	126	138	143	159	170	184	122
	1919	127	189	217	241	259	279	298	320	343	379	414	432	280
		53	87	103	116	126	137	148	160	173	193	212	222	138
22	1917	111	167	196	226	252	271	291	313	338	374	394	414	268
		44	75	91	108	122	133	144	156	170	190	201	212	131
	1919	104	178	207	228	248	268	286	307	331	369	401	423	268
		40	81	97	109	120	131	141	153	166	187	205	217	131

Difference in Gravity of Gasoline Due to Nature of the Crude from which Obtained

Sample No.	Crude	Company No.	City	State	Specific gravity	Degrees Baumé	Distillation* Initial	10 per cent	20 per cent	30 per cent	40 per cent	50 per cent	60 per cent	70 per cent	80 per cent	90 per cent	95 per cent	Dry point	Average boiling point
A. Same Volatility; Different Gravities																			
271	California.......	13	Tucson.....	Arizona.....	0.762	53.7	140	189	203	216	230	241	252	266	284	309	334	352	244
							60	87	95	102	110	116	122	130	140	154	168	178	118
538	Pennsylvania....	83	Portland....	Maine......	0.722	63.9	149	190	203	216	226	239	252	264	282	306	331	360	244
							65	88	95	102	108	115	122	129	139	152	166	182	118
855	Mid-Continent...	69	Tulsa.......	Oklahoma...	0.736	60.2	135	174	196	210	225	235	257	273	295	327	358	385	246
							57	79	91	99	107	113	125	134	146	164	181	196	119
B. Same Volatility; Different Gravities																			
362	Pennsylvania....	20	Wilmington.	Delaware...	0.739	59.4	158	205	223	237	252	266	280	297	316	345	381	417	273
							70	96	106	114	122	130	138	147	158	174	194	214	134
832	Mid-Continent...	240	Muskogee...	Oklahoma...	0.748	57.2	165	201	217	228	244	257	273	289	311	340	369	397	266
							74	94	103	109	118	125	134	143	155	171	187	203	130
294	California.......	92	Los Angeles.	California...	0.771	51.6	127	199	219	237	250	264	279	289	311	340	374	403	266
							53	93	104	114	121	129	137	143	155	171	190	206	130
C. Same Gravities; Different Volatilities																			
479	Mid-Continent...	59	Topeka.....	Kansas.....	0.745	57.9	144	199	223	243	255	271	289	307	329	352	381	410	275
							62	93	106	117	124	133	143	153	165	178	194	210	135
295	California.......	84	Los Angeles.	California...	0.746	57.7	131	176	192	210	225	239	252	273	293	325	361	394	246
							55	80	89	99	107	115	122	134	145	163	183	201	119
691	Pennsylvania....	20	Newark.....	New Jersey..	0.744	58.2	167	216	230	244	257	277	293	313	338	374	394	423	284
							75	102	110	118	125	136	145	156	170	190	201	217	140

* The upper line of figures for each sample represents Fahrenheit temperatures, the lower line Centigrade temperatures. This system will be followed uniformly in all subsequent tables.

a part of the light gas-oil has been distilled off, and the ratio of steam to oil has been greatly increased.

In the Eastern districts, when straight or reduced crude is being distilled, a small quantity of steam is introduced when the gravity of the stream is about 60° Bé. The amount is just sufficient to agitate the contents of the still, prevent cracking, and preserve the color of the stock. Care is taken to avoid an excess of steam during this portion of run, for even a very slight increase, over the amount actually required to attain the desired object, imparts to the kerosene distillate a slight color which is difficult to remove. Moreover, this increase is without apparent influence on yield or quality of final stock. As soon, however, as the stream is "off burning-oil distillate," the quantity of steam employed must be increased as rapidly as possible.[1] Otherwise cracking will occur, which will result in a low yield of stock, dark in color, and generally of inferior quality. By the time the stream is in wax distillate, the maximum quantity of steam should be entering the still. This condition continues until the run is completed. Some refiners advocate high-pressure [2] steam, others superheat; a few operate under vacuum,[3] while several concerns which manufacture excellent stocks employ only low-pressure exhaust. In the writer's opinion, deduced from observations extending through many years, the exact pressure or temperature of the steam employed is immaterial within wide limits, as far as quality and yield of products is concerned. If distillation is otherwise properly conducted, uniformity in steam pressure, a thorough distribution over the still bottom, rapid condensation of vapors evolved,[4] and maintenance of proper still temperature, as shown by the ratio of condensed steam to distillate, will insure high-quality products. The method of steam application is purely an economic feature, dependent on local plant conditions. Control in still operation is further aided by thermometers, preferably of the recording type; but it should be noted that dependence on temperature [5] alone is not a safeguard of yield or quality.

[1] In reducing Pennsylvania crude, the stillman begins to increase the steam supply at about 38° at the worm, gradually opening the valve until at about 35° the quantity of steam entering is still equivalent to 30 to 40 pounds per gallon of wax distillate produced; the ratio varies according to pressure, temperature, and rapidity of distillation.

[2] Silliman (Am. Chem. 2, 18) suggested in 1855 the use of "High Steam" in the distillation of petroleum. Steam at 65 to 100 pounds pressure is most commonly employed in the steam reduction of crude, in present practice.

[3] A few American refineries operate reducing stills under a partial vacuum obtained by the aid of a vacuum pump. The stills for this purpose are generally heavier, smaller, and more strongly braced than the ordinary horizontal crude stills, which they resemble. Considering the cost of their installation, the advantages obtained over properly applied steam are doubtful. Not a few refiners use a steam jet, producing only a very slight vacuum in connection with ordinary stills, and claim that they obtain a better quality of product thereby. Two somewhat recent designs in vacuum stills are those of Steinschneider, United States Patent No. 981,953, 1911; and Schliemann, German Patent No. 227,179, 1909. For a theoretical discussion of the principles involved in vacuum distillation see Gräfe, "Petroleum," 311, 28; Gurwitsch, idem, 4, 265 and 618; also the same author "Wissenschaftliche Grundlagen der Erdölbearbeitung," 124 and 127, 1913.

[4] It is essential for a high yield of quality, steam-refined stock that the wax distillate vapor be condensed and removed as rapidly as it is formed. Any development of pressure tends to liquefy a portion of the vapor. This causes it to drop back into the hot still, "crack," and destroy the test of stock. This is particularly liable to happen during the final portion of the run, when the oil in the still is at its most elevated temperature. For this reason, manifold coils are usually employed for condensation of vapors evolved in reduction. Still more rapid action is sometimes obtained by withdrawing the uncondensed steam from intermediate sections of the worm, just beyond the point where the oil vapor itself has become liquefied. The latter then cools much more rapidly, as the condenser is not required to absorb the latent heat of the steam, in addition to that of the liquefied oil vapor.

[5] Where steam is properly applied, a temperature of 680° F. and even 700° F. is often attained in the manufacture of 630° F. flash Pennsylvania steam-refined stock, without injury to yield or color. On the other hand, a temperature of 600° F. will ruin the color of a stock when steam is improperly distributed, or distillation otherwise wrongly conducted.

The following tabulation is typical of the cuts employed and yields obtained in reducing Pennsylvania crude to 650° F. fire-test steam-refined stock according to present (1921) practice.

Typical Yield of Pennsylvania Crude when reduced to Steam-refined Stock

(Charge 610 barrels 42.4° Bé. crude, run with 60 pounds of steam in horizontal cylindrical crude still; running time twenty-six hours.)

Cut	Grade	Gravity Deg. Bé.	Per cent
Start–54	Gasoline, benzine *	58.7	26.1
54–51	Naphtha	52.5	5.3
51–41	46/47 distillate	46.2	29.8
41–38	300 mineral seal stock	38.2	6.2
38–off	Wax distillate	34.5	18.5
Residue	650-steam-refined stock	26.7	11.9
	Refining loss	....	2.2
			100.0

* Many Pennsylvania refiners distill off a considerable percentage of gasoline, sufficiently sweet to stand the "doctor" test by continuous steam distillation prior to reduction in crude stills. See also p. 345.

Variations of the above method are practiced in several western refineries, operating on semi-paraffin-base crudes. In some cases the crude itself is initially treated and then reduced to steam-refined stock. More frequently the gasoline and light ends are first removed continuously; the residuum obtained, i.e., the fuel oil of the "skimming plant," is then treated and finally the treated fuel is reduced as in Pennsylvania practice. Stocks thus obtained vary in color, physical tests, and lubricating power from grades equal to Pennsylvania products to those of decidedly inferior quality. Their quality depends on the nature of the crude, the extent of treating, and the refining skill employed. Western stocks are usually lower in Baumé gravity, for a given flash and viscosity, than those of eastern origin.

Steam reduction is also generally applied to crudes, more commonly to reduced crudes of decidedly asphaltic base, from which steam-refined stock cannot be economically manufactured. The residuum left in the still from such crudes is generally known as road oil, asphalt flux, or maltha, and naturally varies in asphalt content, and in physical and chemical constants according to the nature of the crude, the extent of reduction, and the quantity of steam employed. In general, it is the object of the refiner to remove as much as possible of the overhead lubricating distillate, and still produce a salable residuum. To this end the temperature and the ratio of steam to distillate must be carefully watched; otherwise the overhead lubricating distillate will be dark-colored and coke-formed, and the asphalt content of the residuum will be so altered in chemical composition as to be no longer suitable for further reduction to solid asphalt, or to serve as a base for the oxidized variety.[1] The overhead lubricating distillates from semi-asphaltic-base crudes generally contain considerable wax, requiring cold pressing for its removal. Those obtained from the purer asphaltic-base crudes of the

[1] For further information on asphalt, see page 787.

Gulf Coast and California districts are for the most part free from wax, and when subsequently refined form the natural low-cold-test oils of the trade.

The refining of semi-asphaltic or asphaltic-base crudes is a somewhat individual problem, depending on the wax content, the extent of reduction desired, etc. The following schedules will give a fair idea of Mid-Continent and Gulf Coast practice. The first represents a semi-asphaltic, and the second a pure asphalt-base crude.

Typical Yield of Oklahoma Crude when Reduced to Asphalt Flux

(Charge 960 barrels, 24.4° Bé., run with 40 pounds of steam in horizontal cylindrical crude still; running time twenty-eight hours.)

Cut	Grade	Gravity, Deg. Bé.	Per cent
Start–37	Prime-white distillate stock...	38.3	3.5
37–32	34/36 gas-oil..............	33.7	9.8
32–31	Wax oil*..................	31.5	20.3
31–20	Wax distillate..............	28.8	44.7
Bottom 20	Asphalt flux................	14.2	19.3
	Refining loss................		2.4
			100.0

* Wax oil is distinguished from wax distillate as being of a crystalline nature and ready for cold pressing, and differs from paraffin distillate in that its pressed portion forms the stock base for neutral oils, and steam-run products, while paraffin distillate, after pressing, forms the base for paraffin oils and dry-run products.

Typical Yield of Texas Crude when Reduced to Flux

(Charge 561 barrels, 19.3° Bé., run with 60 pounds of steam in horizontal cylindrical crude still; running time forty-five hours twenty minutes.)

Cut	Grade	Gravity, Deg. Bé.	Per cent
Start–33	Sour kerosene distillate stock.	37.5	3.7
33–24	Gas-oil....................	26.5	28.4
24–off	Cold-test lubricating distillate.	22 5	35.1
Residuum	Maltha or flux..............	15.4	30.2
	Refining loss...............	....	2.6
			100.0

The lighter wax distillate from a paraffin-asphaltic-base crude is often sufficiently crystalline to be pressed directly; and all of the lubricating distillate from the purer asphaltic base crudes may often be so handled, or may not require pressing at all. In general, the overhead lubricating distillates, from steam-reduced crudes, require to be rerun, or " cracked," before their paraffin-wax content can be successfully separated. " Cracking," in this sense, means simply a rapid rerunning of the distillates in question with a small amount of bottom steam. Its object is to produce the greatest possible quantity of an overhead distillate of good color that will press readily (i.e., contain crystalline wax) but still retain its maximum viscosity. The residuum from a wax

"cracking" still is sold as black [1] oil when obtained from an asphalt-free wax distillate; it is often mixed with fuel oil, road-oil stock, or asphalt flux, as economic conditions and sales may demand. In many refineries the residuum from wax distillate or wax cracking stills is used for fuel at the plant itself. Such material is high in B.t.u. value, and when kept hot and in constant circulation may be handled with little trouble even in gravities as low as 11° to 12° Bé.

After the paraffin-wax content has been removed by cold pressing from the paraffin distillate or wax oil, the pressed distillate is further steam-reduced. It yields, as overhead products, gas-oil and light lubricating distillates, and as a residuum in the still, heavy viscous paraffin or neutral oil stocks, according to the product originally charged. The process of reduction, in its simplest form, consists of distilling off the lighter fractions until the residuum in the still has reached the desired flash and viscosity. The operation is commonly conducted in discontinuous horizontal cylindrical stills, generally termed reducing stills. Reduction is also accomplished continuously, the stills in the battery in such an installation being usually provided with towers, which dephlegmate the overhead light lubricating distillates to products of desired flash and viscosity, and avoid any subsequent reduction, which would be necessary in the simpler batch stills.

In Pennsylvania practice the reduced neutral stock is ready for filtering when pumped from the still, but in Mid-Continent and Coastal crudes it is often necessary to treat it before or after reduction, and in some instances at both points, before filtration.

This course naturally requires a reduction to considerably higher viscosities than those of the finished oils, to allow for treating losses.

The cuts employed in the reduction of lubricating distillates vary widely, depending naturally on the composition of the distillates themselves, the market conditions, and the nature of the inspection which the finished oils must ultimately pass. Thus, where the base requires only a slight filtration to produce the finished oil, it is only necessary to reduce it in the still to the desired flash, and to a viscosity 5 to 15 points[2] higher than that of the filtered oil. On the other hand, if heavy treatment is necessary before filtration, and a light-colored[3] neutral is the final objective, as much as 60 points in viscosity must be allowed at the still for loss in subsequent handling. This obviously requires heavy initial reduction. As such treatment means a decided increase in refining cost, and a decrease in the yield of a desirable product, it is the constant aim of the refiner to maintain color and viscosity, as far as possible, during reduction. To this end even greater care is necessary in maintaining the proper still temperature and ratio of the steam to the overhead distillate, than in the reduction to steam-refined stock. The latter is not usually refined to the same extent as neutral or paraffin oils.

Where the batch system of reduction is practiced, the light overhead lubricating distillates are separated into first, second, and third cuts, and these are subsequently reduced separately. From the light lubricating stocks thus obtained the light, non-viscous and medium-viscous paraffin and neutral oils of the trade are manufactured, after acid treatment or filtration, or in some instances after a combination of the two methods. Such stocks are produced directly from the tower distillates of several continuous processes.

[1] The term "black oil" is rather generally applied to any dark-colored lubricating oil of moderate flash and viscosity, suitable for heavy lubrication, such as that of railroad car journals, gears, cables, etc.

[2] Unless otherwise specified, references to viscosity refer to values obtained on the Saybolt Universal Viscosimeter, in this case operating at 100° F.

[3] The color standards of the National Petroleum Association, now adopted as official by the Committee on Standardization of Petroleum Specifications, Bulletin 5, effective December 29, 1920, are in general use by practically all American refiners. Shades of one, one and one-half, two, and three colors are classed as light-colored oils, two and three color grades being the usual trade colors for the better class of pale neutrals and paraffins.

Assuming a profitable demand for non-viscous and viscous lubricants, the following cuts will give a fair idea of the Mid-Continent practice in the reduction of lubricating oils.

Reduction of Pressed Neutral Distillate to Viscous Red Oil

Cut	Grade	Per cent
Over–37	Prime-white distillate stock	5.3
37–32	32/36 gas-oil	10.3
32–30½	60/70 non-viscous base (1st lubricating cut)	12.8
30½–27½	90/100 non-viscous base (2nd lubricating cut)	22.1
27½–off	180/200 viscous base (3rd lubricating cut)	19.9
Residuum	280 viscous red stock	27.2
	Refining loss	2.4
		100.0

Reduction of 90/100 *Non-viscous Base to* 90/100 *Non-viscous Neutral Stock*

Cut	Grade	Per cent
Over–37	Prime-white distillate stock	10.3
37–32	32/36 gas-oil	26.4
32–off	60/70 non-viscous base (1st lubricating cut)	25.1
Residuum	90/100 non-viscous neutral stock	35.5
	Refining loss	2.7
		100.0

The following is a comparison of the costs of manufacturing non-viscous paraffins produced from a second reduction of overhead bases, with the cost of manufacturing those obtained as test distillates directly from one reduction of pressed distillate, through the agency of the Gray tower.

A further description of the Gray tower is given on page 221, also an illustration on page 219. The following figures were furnished by the Bethlehem Ship Building Corporation, manufacturers of the Gray tower, and are based on market prices effective in the early part of 1921.

Estimated cost of manufacture: Gray towers.—Column *A* gives a statement of cost and yields in all ordinary distillation of "28 Oil"[1] and "30 Oil"[2] from distillation of 1000 barrels (42 gallons) of pressed distillates per day of twenty-four hours; column *B*, statement of cost and yield where Gray towers are used in connection with the ordinary method of distillation. One thousand barrels of pressed distillate per day is the product of 4000 to 5000 barrels of crude oil.

[1] "28 oil," commonly called 28 pale paraffin oil, or 28 pale, when it is a strictly paraffin oil, is usually of the following inspection: 27.5° to 28.5° Bé. gravity, 350° to 360° F. flash, 405° to 415° F. fire test, 90 to 100 viscosity. Frequently a non-viscous neutral oil of 90–100 viscosity is substituted for the true paraffin oil, with generally satisfactory results in most instances.

[2] "30 oil" or 30 pale paraffin oil resembles 28 pale paraffin oil in general characteristics, but is usually slightly lower in flash and of 60 to 70 viscosity. It is used interchangeably with 60 to 70 non-viscous neutral oil.

	(*A*) Barrels	(*B*) Barrels
Yield of 30 stock from distillate, 20 per cent	200	...
Yield of 28 stock from distillate, 12 per cent	120	...
Yield of 30 oil from distillate, 12 per cent	...	120
Yield of 28 oil from distillate, 7 per cent	...	70
Yield of untreated 30 oil from redistillation of 200 barrels of 30 stock, 40 per cent	80	...
Yield of untreated 28 oil from redistillation of 120 barrels of 28 stock, 50 per cent	60	...

Cost and Yield of " 30 " and " 28 Oil " in Ordinary Distillation Practice

	" 28 Oil "	" 30 Oil "
Redistillation of stocks at cost of 25 cents per 100 gallons, including interest on investment and depreciation	$12.60	$21.00
Yields of untreated oils, 40 per cent and 50 per cent	60 barrels	80 barrels
Cost of treating at 80 cents and 90 cents per 100 gallons	$22.68	$26.88
Yields of finished oil 90 per cent and 85 per cent	2142 gallons	3024 gallons
Value of oil lost in treating, based on gas-oil value at 4 cents per gallon, 336 gallons and 378 gallons	$15.12	$13.44
Total operating cost	$50.40	$61.32
Operating cost per gallon of finished oil	.0235	.0203
Assuming raw material to be worth 4 cents per gallon as gas-oil, total operating cost will be	.0635	.0603
Possible profit per gallon, based on selling price of 8 and 9 cents per gallon respectively	.0265	.0197
Possible profit per day	65.76	59.57
Possible profit per year	20,717.00	21,733.00

Cost and Yield where Gray Towers are Used in Connection with the Ordinary Method of Distillation

	" 30 Oil "	" 28 Oil "
Yield of untreated " 30 " and " 28 " oils	120 barrels 5040 gallons	70 barrels 2940 gallons
Cost of treating at 70 and 80 cents per 100 gallons	$35.28	$23.52
Yields of finished oil 92 per cent and 88 per cent	4637 gallons	2587 gallons
Value of oil lost in treating based on gas-oil at 4 cents per gallon 403 and 353 gallons	$16.12	$14.12
Total operating cost	$51.40	$37.64
Operating cost per gallon	.0124	.0145
Total cost per gallon, assuming raw material to be worth gas-oil at 4 cents per gallon	.0524	.0545

Somewhat comparable to the reduction of pressed distillate is the manufacture of amorphous wax and petrolatum stocks. The former is obtained from a straight reduction of heavy wax distillate, its usual melting point being 90° F., the latter is the result of a mixture of heavy wax distillate and rod wax,[1] cold-settled wax or centrifuge stock,[2] or B. S.[3] from a paraffin-base crude, and its melting point is usually 115° F. In each instance a large quantity of steam is used in the distillation, and the temperature of the still is maintained at such a point that only the lighter fractions will be progressively distilled. The objective is a maximum yield of residuum product. Considerable refining skill is required in the production of these stocks, in order to produce a high yield of base, sweet to the taste, of required melting point, non-crystalline in texture, and yet not too "salvy" to show a certain firmness and slightly fibrous quality. Such reductions may require forty hours or more, and even in small stills this interval may be exceeded before the bottoms are judged sufficiently sweet to be pumped out and

Fig. 153.—A battery of 18 reducing stills.

ready for filtration. The sweet amorphous base is filtered to a light color for soap stock,[4] or neutral paper stock. From the petrolatum stock is made the official petrolatum

[1] This substance, when settled and freed from impurities, is a dark brown, amorphous wax of 170° F. flash, 240° F. burning test, and 124° F. melting point. As obtained in its crude state, it is a light yellow, pasty mass, mixed with water. It collects on the rods and casing of many Pennsylvania wells, annoying the pumper and interfering with production. It is usually brought to the refinery mixed with dirt, leaves, etc., indicating the slight care bestowed on its collection.

[2] These products are obtained in the manufacture of cold-settled or "bright" stocks. The first named is obtained from the older settling process, and the second from the more rapid centrifugal method of separation. The wax obtained from the latter process is of somewhat higher melting point than that obtained simply by cold-settling.

[3] The term "B. S." (bottom settlings) is quite generally applied to the emulsions of oil, water, and mud that settle out of crude in storage, and which would have no value as a petrolatum base. The "B. S." from Pennsylvania crude is, on the other hand, largely an emulsion of water and amorphous wax, and when properly freed from foreign matter forms an excellent base for the light yellow and darker grades of petrolatum.

[4] Mineral soap or paper stocks are usually sweet, light-colored amorphous waxes, and are used in the manufacture of soap and in the saturation of waxed papers. While mineral soap stock is unsaponifiable, the use of small percentages of it in the manufacture of soap cannot be considered an adulteration, since its judicious incorporation adds a certain softness and prevents rapid drying of the soap in question.

of the United States Pharmacopœia, otherwise known as petroleum jelly, or "Vaseline."[1] The cuts employed in the reduction of amorphous stocks are generally the same as for crude, provided the color of the distillates permits. The steam is introduced as soon as the contents of the still "settles to boil."[2] Great care is taken to maintain the proper ratio of steam to the overhead distillate throughout the entire run, and thus prevent the raising of the higher melting-point waxes.

Besides being employed in the standard methods of distillation, steam is also used in certain cracking and reducing processes having as their objective an increased gasoline production. This use of steam is described in the chapter devoted to this subject.[3]

FIG. 154.—A row of condensers.

The products of steam distillation comprise both intermediates and finished grades, the latter predominating. A brief description of the more important ones follows.

Products of Steam and Reducing Stills

Gasoline.—This product as derived from sweet crude, has already been mentioned in the list of grades obtained from dry-run crude stills, and while it is obtained in increased quantity where steam is used in crude-reduction, by far the greater amount of gasoline is still finished in the so-called steam stills. The fancy and more volatile grades are entirely so obtained, while the standard automobile grades also have steam-still stock as their principal component.

Exclusive of unimportant quantities of special solvents and illuminating standards,

[1] The term "Vaseline" is strictly applicable only to the preparations of the Cheesbrough Manufacturing Company; but with frequent use it has acquired a generic sense apart from its proprietary significance.

[2] "Settles to boil" is a commonly used refinery expression signifying that the original entrained water in the charge has been nearly distilled off, and the temperature is probably passing 300° F. When this occurs the contents of the still begins to mount rapidly in temperature without bumping or pounding.

[3] See p. 345. A battery of reducing stills, together with their corresponding condensers is shown in Figs. 153 and 154, respectively.

such as cymogene,[1] rhigolene,[2] pentane,[3] etc., about the highest gravity of straight-run gasoline sold is the 86° to 88° gasoline produced by a few Pennsylvania refiners and used principally for gas lighting systems. Naturally it is sold in relatively small quantities. The next grade offered to the trade, also a Pennsylvania product, is the so-called 74° to 76° gasoline, which finds use as a gas-engine fuel, in light-producing systems, and as a special solvent for gums, rubber, etc. A Mid-Continent grade of somewhat lower gravity, but superior in volatility [4] to much of the 74° to 76° gasoline offered on the market, finds limited use as a rubber solvent. The 66° to 68° gasoline formerly widely sold as a standard automobile gasoline, will now generally pass the United States Government aviation specifications. It also finds considerable use for street and plumbers' torches, mantle lights, safety lamps, cleaners' naphtha, etc. The equivalent of this grade is produced from the Mid-Continent field in somewhat lower gravities.

The next grade commonly offered to the trade is the so-called navy, or motor, gasoline, produced from all fields, and varying in gravity from 62° to 56° Bé., according to the source of the crude and the refining methods employed. While this product is sold in enormous quantities, it is far eclipsed in use by the ordinary automobile grade ranging from 58° to 54° Bé. and from 437 to 450 F. end-point. It is sold under various trade names, its inspection varying in different localities.[5] This product is for the most part a mixture of casing-head or absorption condensate or refined "cracked" gasoline, with straight-run refinery grade; when it is properly blended no fault can be found with its quality. Below the grade of standard gasoline there are various batching gasolines intended for blends. Solvent naphthas and turpentine substitutes with closer distillation range, have already been discussed.

The United States Government specifications for aviation gasoline, domestic grade, as adopted in the report of the Committee on Standardization of Petroleum specifications, Bulletin 5, effective December 29, 1920, are as follows:

Specifications for Aviation Gasoline, Domestic Grade

1. This specification covers the grade of gasoline used by the United States Government and its agencies for aviation fuel, where the fighting grade is not required.
2. The gasoline shall be free from undissolved water and suspended matter.
3. Color: The color shall be water-white.
4. Doctor test: The doctor test shall be negative.
5. Corrosion test: One hundred cubic centimeters of the gasoline shall cause no

[1] Cymogene, the lightest commercial product obtained from petroleum, usually ranges from 110° to 100° Bé., boiling point 32° F., and consists largely of butane. It finds use as a local anæsthetic, and is also employed in certain types of refrigerating machines.

[2] Rhigolene, also applied as the equivalent of cymogene, is an exceedingly volatile fraction, ranging between 100° and 90° Bé., boiling point 65° F., and consists largely of pentane. It is also employed to produce local anæsthesia. It was introduced by Bigelow (Chem. News, 13 (1866), 244). Pennsylvania petroleum is said to yield 0.1 per cent of this substance.

[3] Pentane in its pure state is of 94° Bé., 100.4° F. boiling point, and is prepared for the trade in a high degree of purity. It finds use as a special solvent, and as an illuminating standard for candle-power.

[4] The distillation range of a 69° to 70° Bé. Mid-Continent gasoline sold as a rubber solvent is as follows:

Distillation Range of 68° to 70° Mid-Continent Gasoline, Degrees F.

Initial boiling point	110	40 per cent	174	80 per cent	220
10 per cent	143	50 per cent	185	90 per cent	224
20 per cent	158	60 per cent	195	End-point	286
30 per cent	162	70 per cent	208		

[5] See p. 362.

gray or black corrosion and no weighable amount of deposit when evaporated in a polished copper dish.

6. Unsaturated hydrocarbons: Not more than 2.0 per cent of the gasoline shall be soluble in concentrated sulphuric acid.

7. Acid heat test: The gasoline shall not increase in temperature more than 10° F.

8. Distillation range: When 5 per cent of the sample has been recovered in the graduated receiver, the thermometer shall not read more than 75° C. (167° F.) or less than 50° C. (122° F.)

When 50 per cent has been recovered in the receiver the thermometer shall not read more than 105° C. (221° F.)

When 90 per cent has been recovered in the receiver the thermometer shall not read more than 155° C. (311° F.)

When 96 per cent has been recovered in the receiver the thermometer shall not read more than 175° C. (347° F.)

The end-point shall not be higher than 190° C. (347° F.)

At least 96 per cent shall be recovered as distillate in the receiver from the distillation.

The distillation loss shall not exceed 2 per cent when the residue in the flask is cooled and added to the distillate in the receiver.

9. Acidity: The residue remaining in the flask, after distillation is completed, shall not show an acid reaction.

All tests shall be made according to the methods for testing gasoline adopted by the Committee on Standardization of Petroleum Specifications.

The distillation range of a 63° to 64° Bé. Mid-Continent gasoline, sold as a domestic aviation grade, is as follows:

Distillation Range, Degrees F.

Initial boiling pt. .	110	40 per cent	197	80 per cent	245
10 per cent	155	50 per cent	207	90 per cent	272
20 per cent	172	60 per cent	218	End-point	330
30 per cent	185	70 per cent	230		

Motor Gasoline

The United States Government specifications for navy gasoline, or motor gasoline, as it is now called, as adopted in the report of Committee on Standardization of Petroleum Specifications, Bulletin 5, effective December 29, 1920, are as follows:

1. This specification covers the grade of gasoline used by the United States Government and its agencies as a fuel for automobiles, motor boats, and similar engines.

2. The gasoline shall be white in color and free from undissolved water and suspended matter.

3. *Distillation range*: When the first drop has been recovered in the graduated receiver, the thermometer shall not read more than 60° C. (140° F.)

When 20 per cent has been recovered in the receiver the thermometer shall not read more than 105° C. (221° F.)

When 50 per cent has been recovered in the receiver the thermometer shall not read more than 140° C. (284° F.)

When 90 per cent has been recovered in the receiver the thermometer shall not read more than 190° C. (374° F.)

The end-point shall not be higher than 225° C. (437° F.)

At least 95 per cent shall be recovered as distillate in the receiver from the distillation.

All tests shall be made according to the methods for testing gasoline adopted by the Committee on Standardization of Petroleum Specifications.

Benzine.—The benzine obtained by steam distillation differs from that obtained by dry-heat running only in being usually of a better color. It is invariably refined into the gasolines and naphthas mentioned above.

Kerosene distillate.—This product, like the foregoing, differs but little from the natural burning-oil distillate obtained by dry-heat stilling. It is usually of slightly better color, but the color is more fixed and more difficult to treat to water-white grade than in the dry-run product. For this reason the minimum of steam [1] is commonly employed during distillation, even in so-called reducing runs.

Mineral seal distillate.—This grade, cut between kerosene distillate and gas-oil, is widely used as a solvent oil in gasoline absorption processes. From a few crudes, notably Pennsylvania, this class of distillate is of excellent burning quality even at 300° F. fire test, and, when treated, forms the 300 Mineral Seal or Mineral Colza oil of the trade. This is used largely in signal lamps and for lighthouse illumination.

Gas-oil.—The greater portion of the gas-oil supplied to the trade is a by-product of the manufacture of paraffin and neutral oil stocks. It consists partly of a distillate intermediate between heavy burning-oil and lubricating distillate, but mostly of the light fractions distilled from the lubricating distillates themselves during reduction to test stocks. It is offered to the trade in gravities of 34° to 36°, 32° to 34°, 30° to 32°, and 28° to 30° Bé., also very commonly as 32° to 36° gas-oil, which usually meets the U. G. I. specifications.[2] A typical distillation of such gas-oils is given below:

In the tabulation following it will be noted that all of the gas-oils produced from Mid-Continent crude although varying in gravity, meet the U. G. I. specifications, in regard to distillation range, except Sample No. 4.

Distillation Range of Typical Mid-Continent Gas-oils

No. of sample: Bé. gravity	1 32.7°	2 33.1°	3 34.4°	4 35.1°
	Degrees F.	Degrees F.	Degrees F.	Degrees F.
Initial boiling point	510	492	458	318
10 per cent	541	525	497	382
20 per cent	573	558	524	443
30 per cent	601	591	576	539
40 per cent	615	607	586	561
50 per cent	630	625	597	586
60 per cent	642	641	614	606
70 per cent	661	664	633	637
80 per cent	678	690	664	677
90 per cent	698	716	674	698
Final boiling point	726	705	694	721

[1] See description of refining Pennsylvania crude, p. 353.

[2] The United Gas Improvement Co. specifications, covering gas-oil suitable for enrichment purposes are as follows: Not over 0.5 per cent coke, not over 0.5 per cent sulphur; and 85 per cent to distill between 400° and 700° F.

Distillation Range of Miscellaneous Gas-oils

Source of crude	Bé. gravity	Start to 300° F.	300° to 350° F.	350° to 400° F.	400° to 450° F.	450° to 500° F.	500° to 550° F.	550° to 600° F.	600° to 650° F.	Above 650° F.
Kentucky.......	35.9°	0.0	0.0	0.0	0.0	6.0	34.8	31.3	18.6	9.3
Pennsylvania....	33.9	0.0	0.0	0.0	1.0	1.6	9.7	7.8	25.2	54.7
Ohio............	35.2	0.0	2.5	7.0	13.0	15.4	16.6	13.7	21.3	10.5
Texas...........	29.3	0.0	3.1	4.5	9.9	20.1	24.5	17.7	12.1	8.1
California.......	32.3	4.0	5.0	6.2	9.2	12.8	28.8	26.4	7.6	0.0
Russia..........	30.4	0.0	0.0	0.4	0.8	7.4	18.8	25.8	21.4	25.4
Rumania........	29.6	2.2	6.5	7.9	10.3	12.4	21.0	11.3	9.2	19.2

Wax distillate.—This intermediate, the primary base for paraffin wax and neutral oils, is an amorphous product, and for the most part requires rerunning before pressing. As obtained from reducing stills, wax distillate is commonly of 27° to 35° Bé. gravity[1] 175° to 250° flash, 235° to 310° fire test, 60 to 80 viscosity at 100°, 60° to 70° cold test and varies in color from pale yellow to dark brown. The distillates obtained from semi-asphaltic crudes darken rapidly on exposure to air.

Wax-oil.—This product is a second intermediate obtained from the distillation of wax distillate. It is crystalline in nature, and comparable with paraffin distillate produced by the dry-heat process. It is the immediate base from which paraffin wax and neutral oils are manufactured. As obtained from wax-cracking stills, it is usually of 27° to 33° Bé. gravity, 200° to 275° flash, 260° to 335° fire test, 70 to 90 viscosity at 100°, 60° to 70° cold test, and is of a pale yellow color.

Reduced wax distillate.—This is also an intermediate, and is amorphous in nature. It is the filtration base for soap stocks and petrolatum admixtures. Reduced to 90° F. melting point, as produced from Pennsylvania wax distillate, it is of 33.3° Bé. gravity, 385° flash, 450° fire test, 40 viscosity at 212° F., and of a dark yellow color.

Petrolatum stock.—This material, the base for all petrolatum, varies from light yellow to dark green in color, according to the nature of the materials used in its manufacture. Its usual properties are approximately as follows: 32° to 33° Bé. gravity, 400° to 410° flash, 40 to 50 viscosity at 212° F. It should possess only a faint odor, be sweet to the taste, and show freedom from suspended impurities.

Steam-refined stock.—This product, when not above 600° fire test or 160 viscosity at 212°, serves as an intermediate from which filtered and bright stocks are manufactured. Stocks of higher flash and viscosity are usually sold directly as finished steam-cylinder lubricants.[2] According to the source of manufacture, the various stocks on the market differ somewhat in gravity, color, and viscosity for a given flash and fire test. Where they are sold on viscosity they show a slight variation in other constants. Flash and viscosity being equal, color, cold test, and freedom from tar determine the quality

[1] The average gravity of Mid-Continent wax distillate is 28° to 29° Bé., that from Pennsylvania crude running 33° to 34° Bé.

[2] For distinctly mechanical lubrication, such as transmission and differential lubricant, and also for certain classes of steam and heavy internal-combustion engine lubrication, steam-refined stocks are used as produced at the still. Most of the product of the various grades is sold blended with paraffin or neutral oils as engine, harvester, and gas-engine lubricants, or is compounded with animal fats for steam-cylinder lubrication. Stocks of 600° and 630° flash are used in superheated steam lubrication.

and price. The appended tabulation gives an idea of the characteristics of stocks refined from several sources.

In the following list, only typical superior stocks are included, although it is recognised that the cheaper grades of 200 or higher viscosity at 212° F., heavy in asphaltic and tarry content, fill an important place in the industry.

Characteristics of Typical Steam-refined Stocks

Source	Bé. gravity	Flash, degrees F.	Fire, degrees F.	Viscosity, 212° F.	Color	Cold test
Mid-Continent......	22.2°	535°	600°	160	Bright green	55
Lima..............	21.0	535	600	170	Green	40
Pennsylvania.......	29.5	540	600	160	Bright green	35
Pennsylvania.......	26.7	580	650	180	Green	35
Pennsylvania.......	25.5	600	680	230	Dark green	30
Pennsylvania.......	25.0	630	700	245	Dark green	30

Asphalt flux.—As steam-refined stock is produced from a paraffin-base crude, asphalt flux is obtained from an asphalt-base crude. There is naturally no fixed line of demarcation; fluxes low in asphalt are marketed as steam-refined stocks, in periods of acute demand, and conversely, cheap stocks become flux products and road oil bases, in a slack lubricating-oil market. Asphalt flux is often sold directly as road oil, and it forms the base for further reduced malthas, pitches, and oxidized asphalts, the manufacture of which is discussed in another chapter of this volume.[1] The characteristics of several typical Mid-Continent fluxes are given below. In the lighter gravities such fluxes are sold as road oils without further admixture.

The average asphaltic content of the fluxes listed below is about 76 per cent and their paraffin wax content 2.5 per cent. All three yield fair grades of oxidized asphalt or pitch when reduced with steam and air.

Characteristics of Typical Mid-Continent Asphalt Fluxes

Bé. gravity	Flash, degrees F.	Fire, degrees F.	Viscosity, 212° F.	Sol CS_2 per cent	Sol. 76° naphtha, per cent	Vol. seven hours per cent
16.0	350°	480°	......	99.6	95.42	5.62
14.0	430	520	270	99.5	95.31	3.33
12.0	450	550	478	99.4	94.72	1.56

Road oil.—Although a considerable amount of asphalt flux of high gravity, i.e., 18° to 20° Bé., containing a rather high percentage of paraffin wax, is marketed as road oil by such plants as are without lubricating departments and facilities for further reduction; yet the greater part of the road oil sold is either produced from essentially wax-free crudes such as those of the Gulf Coast districts, or is compounded from heavy fluxes (from which the greater part of the wax has been removed) and the gas-oil by-

[1] See page 787.

products from the reducing stills. A table showing characteristics of several typical road oils is appended. The reader is referred to the chapter on Testing Methods for information as to solubility tests.[1] While road oil specifications vary considerably, and embrace a wide range of chemical and physical tests, the following data may be accepted as typical for oils of this class, which are produced in enormous quantities from the Mid-Continent and Gulf Coast districts.

The resemblance between road oil and flux will be noted by comparing the following table with that immediately preceding:

Typical Road Oil Characteristics

Physical properties:			
Grade	16°–17°	18°–19°	20°–21°
Gravity, specific	0.9575	0.9440	0.9290
Gravity, Bé	16.3°	18.4°	20.8°
Flash, Cleveland cup	260° F.	240° F.	200° F.
Fire, Cleveland cup	300° F.	275° F.	235° F.
Viscosity, Saybolt at 130° F.	400	200	100
Viscosity, Engler at 50° C.	14.6	7.00	4.52
Chemical properties:			
Asphalt content (per cent)	75	65	50
Solubility in CS_2 (carbon disulphide) vapor	99.50	99.55	99.60
Solubility in $CHCl_3$ (ch oroform) vapor	99.64	99.65	99.66
Solubility in CCl_4 (carbon tetrachloride) vapor	99.50	99.50	99.50
Solubility in $(C_2H_5)_2O$ (ethyl ether) vapor	99.25	99.30	99.32
Solubility in 76° naphtha	97.59	97.60	97.80
Fixed carbon (per cent)	0.05	0.04	0.02
Ash	10	7	5

In general. the art of stilling, whether operating dry or with steam, calls for close attention to numberless details. It is necessary to watch the condition of the still bottoms, and to make sure that manneck and top plates are bolted down tight, that stills are charged to the proper level, that condensing water is properly distributed, that pumping-out lines are clear at all times, etc. If steam is used, close observation of the size of the streams, the temperature of the still contents, and the pressure of the steam itself (particularly if irregular) must be maintained at all times. The safety-valve must be watched for escaping gas; personal exposure to sulphide gases evolved from certain crudes and distillates must be avoided; finally, the stillman must be ever on the watch for improperly opened or closed cocks or valves.

As to operation labor, one stillman per shift of eight hours can attend from ten to twelve discontinuous, ordinary, horizontal crude stills running dry heat, and can more easily look after an equal number of continuous stills. The handling of the same number of tower or lubricating oil stills requires the service of a helper, particularly in the first instance when stills are about to coke, and in the second when making the final flash or viscosity test desired. Where gas or oil is used for fuel the stillman looks after his own fires, but where coal is the source of heat, one fireman is commonly employed for three 1000-barrel stills, or for four 600-barrel stills per shift of eight hours. The number of ash wheelers depends on local conditions, such as installation or absence of conveying systems, etc. Still cleaning is usually piece-work labor; a certain price

[1] See page 715.

previously determined to be a fair average is set for crude stills, coke stills, etc. One or two pumpers per battery of run-down tanks are usually employed on each shift. The frequency of pumping required, the distance between tanks, etc., govern the number of pumpers employed. In the larger plants there is usually a head stillman, or stillman foreman on each shift, in charge of several batteries. He is directly responsible to the superintendent, has full authority over the operatives in his department, and is held generally accountable for the labor and process. All repairs are handled by the mechanical department on the order of the stillman foreman.

Chemical Treatment

Chemical treatment, in its application to refining, is usually termed "treating" and may be defined as the art of purifying petroleum intermediates by agitation with chemicals, or by physical absorbents, in a specially constructed type of apparatus,

Fig. 155.—A group of six agitators.

known as an "agitator," or "washer."[1] A group of agitators is illustrated in Fig. 155. In the case of light oils and gasolines, treating is usually practiced to remove objectionable sulphur and nitrogen compounds,[2] and incidentally to improve the burning quality, odor, and color. With lubricants and paraffin wax, the objects of treating are the lowering of the sulphur content, the removal of the carbon, and a general improvement in the appearance, resulting in a finished oil of better color and odor, with superior lubricating qualities.

[1] The term "agitator" is practically universally applied in this country to the upright, lead-lined, conical-bottom cylindrical tank in which treating takes place, the name "washer" being in general use abroad for the same type of apparatus. Both names are suggestive of its use. For construction details of various types of agitators, see Figs. 74 and 75, pp. 187-189.

[2] These vary from easily removable, dissolved, hydrogen sulphide gas to complex alkyl mercaptans and thio ethers, eliminated only with the greatest difficulty. For a description of the sulphur content of petroleums, see Engler, Chem. Zeitung, 20 pt. 2 (1896), p. 197; for a consideration of the sulphur compounds in American petroleums, consult Mabery and Quayle, Jour. Soc. Chem. Ind., 19 (1900), p. 305; and Proc. Am. Acad., 41 (1905), p. 87; Mabery and Smith, Am. Chem. Jour., 13 (1891), p. 233, and 16 (1894), p. 83. Concerning the nitrogen compounds, see Mabery and Hudson, Am. Jour. Sci., 1894, p. 250; Chlopin, Berichte, 33, pt. 3, 1900, p. 2837.

The chemicals used in treating are sulphuric acid (oil of vitriol) [1] sulphurous acid,[2] sodium hydrate (caustic soda) solution, sodium plumbate "doctor" solution, sodium carbonate (soda-ash) solution,[3] ammonium hydrate (ammonia water), and calcium hypochlorite (chloride of lime) solution. Sulphur, litharge,[4] and various unimportant substances too infrequently used to warrant mention, are also employed. The principal physical absorbents are fuller's earth, bauxite, bone and blood chars and silica gels.

Application of "Treating" to Various Kinds of Distillate

For convenience in discussion, treating may be classified under three headings, as it is applied to: (*a*) benzine, gasoline, and naphtha; (*b*) kerosene distillate and like products; (*c*) lubricating oils and paraffin wax. In the treatment of benzine, 1½ to 3 pounds of 66° sulphuric acid is commonly employed to the 42-gallon barrel. "Sludge" acid which has been previously used in burning-oil treatments is often substituted. With benzines of low sulphur content, a simple neutralization after a short wash renders the benzine ready for steam stilling. Sulphur-bearing products, on the other hand, require a sodium plumbate "doctor" treatment after washing, varying in strength according to the percentage of sulphur present.[5] Water-white gasolines and naphthas of marketable end-point, but reactive to the "doctor" solution, usually require no acid and only a light sodium plumbate treatment. If the sulphur does not readily precipitate as lead sulphide after blowing for some fifteen to twenty minutes with the sodium plumbate solution, the addition of a small quantity of free sulphur [6] will usually cause the desired precipitation. While lightly compressed air, obtained through the agency of a low-pressure blower, is used for agitation purposes for all treatments in many refineries, the more efficient adopt some mechanical form of mixing for handling their lighter products, thus avoiding loss by volatilization. Mechanical stirrers are used in some refineries, in others the acid is circulated by means of a centrifugal pump, while in still others a continuous counter-current system of treatment is employed.

In the treatment of sour kerosene distillates, an excess quantity of sodium plumbate solution following a heavy acid treatment [7] is employed. The object is to saturate the

[1] The concentrated commercial grade of 66° Bé., 92.5 to 93.0 acidity is most commonly employed, although restored acid of the same strength is used by many plants possessing acid-recovery systems. Weaker acidities are used in special instances and fuming acid and even sulphuric anhydride are employed in the treatment of certain aromatic distillates.

[2] Sulphurous acid is used in the liquid state at low temperatures in the Edeleanu process. It acts rather as a physical solvent than in a chemical capacity. A detailed description of this process occurs on page 392 of this section.

[3] Sodium carbonate and sodium hydrate solutions may be used interchangeably where neutralization of acid is the only objective. For some unexplained reason, due doubtless to impurities in commercial caustic, better colors can sometimes be obtained where soda-ash solution of equal alkaline equivalent is employed.

[4] While litharge (plumbous oxide) is chemically identical in its several physical forms, only those grades should be employed for refining purposes, that prove their superiority by actual trial. While apparently all sodium plumbate solutions of equal strength exert the same desulphurising action, the excess of suspended litharge commonly employed varies considerably in its action according to its physical state, and for this reason a preliminary trial is suggested.

[5] Sodium hydrate solutions of 8°–16° Bé. saturated with litharge are commonly employed as sweetening agents. An excess of litharge is also frequently used, the alkaline solution apparently acting as a carrier, although there appears to be a certain amount of direct action as well.

[6] The action of free sulphur in causing precipitation or "breaking" of the lead sulphide is obscure. It apparently acts as a catalyst in some instances, and in others combines with the oil, replacing the sulphur thrown out with the lead. An actual sulphur determination shows no change in sulphur content before and after precipitation, although the final oil is now sweet in reaction.

[7] By operating at low temperatures, i.e., between 38° F. and 60° F., Robinson discovered that by using an acid stronger than 66°, not more than 60 pounds and not less than 20 pounds to the barrel being used, the objectionable sulphur compounds can be completely removed from difficultly sweetened Lima and Texas distillates. See C. I. Robinson, U. S. Patent No. 910,584, January 26, 1909.

distillate with as much lead oxide as it is able to absorb. A subsequent redistillation renders the oil sufficiently sweet to finish with 66° acid and sodium plumbate solution to a water-white kerosene of .060 per cent sulphur, sweet to the "doctor" solution.[1] "Sweet" distillate, or the ordinary kerosene distillate obtained from a low-sulphur crude, is treated with from 2 to 8 pounds of acid to the barrel, the latter being applied in one or more portions according to the nature of the distillate, the sulphur content, and the finished color desired. Assuming the distillate to be once run, of 0.120 per cent sulphur, and 21 color [2] to be desired on the finished kerosene, the acid would be commonly applied in two portions or "dumps." The "water acid," half a pound to the barrel, is applied merely to dry the distillate. After blowing for fifteen minutes it is allowed to settle for a short period, withdrawn, and followed by the first portion or "dump," usually of from 2 to 4 pounds to the barrel. After forty-five minutes of agitation, the agitator is allowed to stand from an hour and a half to two hours, the sludge is withdrawn, and the second acid, generally equal in quantity to the first, is applied. The last acid is blown from forty-five to sixty minutes, settled for two hours and withdrawn; and the washing is begun with cold water, followed by hot as soon as the greater portion of the entrained sludge is washed away. Washing is continued for two hours or more (less in smaller agitators) and is followed by the neutralizing alkaline solution. If sodium plumbate solution is employed, as would naturally be expected with an oil requiring the acid treatment described, agitation is maintained for from thirty to forty minutes, or until the absorbed lead separates or "breaks" as lead sulphide. The action is aided by free sulphur, steam, or in some instances chloride of lime.

The schedule on the next page gives a fair idea of the time required in treating a batch of distillate of the nature described. Less resistant distillate often requires only 2 pounds of acid to the barrel and finishes in less than half the time stated:

In recent years the batch process for treating oils has been largely replaced by a continuous process, especially in the case of light distillates. As used by the refineries of the Standard Oil Company (N. J.), this continuous process is operated as follows:

Oil is pumped through a Venturi meter which continuously records the amount introduced into the system. The oil is then thoroughly mixed with sulphuric acid which is also pumped continuously through another Venturi. The mixture of acid and oil flows through a series of tanks of approximately 200 barrels capacity each, designed to facilitate the settling of the sludge to the bottom of the tanks. The sludge from these tanks is drawn off continuously and the oil overflows from the top of each to the next tank.

Usually about four of these tanks are required for settling out all of the acid sludge. The oil from which the sludge has been completely settled now flows into a series of wash tanks in which it is spray-washed by water introduced at the top of the tanks. In these tanks the sour water is drawn off from the bottom and the oil overflows from the top. The oil then passes into a series of sweetening tanks where it is thoroughly agitated with sodium plumbate solution. It then passes to other settling tanks and finally leaves the system as a treated and sweet product.

As the entire series of tanks used in the continuous process is air-tight, evaporation is prevented from the time the oil enters the system until it leaves. As contrasted with that of the batch-treating process, this smaller evaporation loss constitutes one of the greatest advantages. Increased capacity is also an important advantage.

Aromatic distillate stock is commonly treated at about 200° F., starting with 66°

[1] This method was employed by H. W. Kittredge, operating on Canadian distillates prior to the general introduction of the Frasch method, and produces a water-white kerosene of 0.040 per cent sulphur, from a crude containing 0.45 per cent of this objectionable product.

[2] Reference is here made to the colors as determined by the Saybolt Universal Chromometer for color shades of refined oils, as adopted by the Committee on Standardization of Petroleum Specifications, Bulletin 5, effective December 29, 1920.

Typical Treating Schedule

(Charge 2500 barrels, 44.3° Bé., 150 water-white distillate)

	Hours	Minutes
Charging agitator	1	45
Cooling distillate *	2	15
Settling contents	1	0
Water-acid blow	0	15
First-acid blow	1	0
Settling acid	1	15
Second-acid blow	1	0
Settling acid	1	45
Washing	2	45
Settling	1	15
Neutralizing and sweetening	1	0
Settling	3	0
Claying †	1	30
Settling	1	30
Washing out clay	1	20
Dropping to bleachers	1	30
Total time consumed	24	5

* Distillate treated above 70° F. is apt to lose two or three points in color, and where possible is cooled to 62° F. to obtain best results.

† The claying of oil, accomplished by filtration, or more commonly by agitation with from 1½ to 2 pounds fine fuller's earth flour to the barrel, removes "floc," and generally improves the burning quality. A clayed oil invariably shows lower in combined acid than one not so treated.

acid, continuing with this until no further action is apparent, and finishing with 15 per cent fuming acid, in quantity approximately equal to 40 pounds of acid per barrel. This results in a treating loss of from 10 to 12 per cent. A variation in method is to replace the fuming acid with sulphuric anhydride direct. The treated distillate stock obtained by either method is neutralized in the ordinary way, rerun, and finished with 2.3 pounds of ordinary 66° acid. The aromatic compounds dissolved as sulphonates in the sludge are ultimately recovered.

Reduced crude, fuel oil, or other steam-refined stock base is commonly treated in an unlined agitator, constructed with a sharp cone, so that the large quantity of sludge produced will settle readily and be easily withdrawn. Treatment is effected at temperatures ranging from 75 to 150° F., 66° acid being commonly employed, in quantity varying from 10 to 30 pounds per barrel, to secure the desired asphalt removal. Treating losses range from 6 to 20 per cent. Neutralization takes place in a second or transfer agitator, which is commonly lead-lined. In the treatment of residual products the objective of the refiner is to obtain a green-colored base that will not darken in the subsequent steam reduction, and at the same time to avoid an excessive treating loss. Low temperature treatments favor color, but retard acid separation, while high temperatures cause sulphonation and subsequent difficulty in settling the emulsions in the transfer agitator.

Paraffin and neutral stocks, like reduced crudes, are treated in unlined lubricating agitators. While 98 per cent and fuming sulphuric acids are used on certain Gulf Coast distillates, 66° acid is most commonly employed. As in the application to kerosene distillate, the acid is generally applied first as water acid, then in one or two portions, in quantity depending on the nature of the distillate and the ultimate color desired. Non-viscous lubricants require from 5 to 8 pounds and viscous stocks from 15 to 20 pounds of 66° acid to the barrel. In general, a much longer interval between acid " dumps " is necessary for settling in the treatment of lubricating oils than in burn-

ing-oil distillates. Intervals of 6 or 7 hours are not infrequent in practice. Another essential difference consists in the addition of a small amount of water, usually in the form of a spray, toward the end of the second acid. Blowing is then continued for an additional hour, or until the acid " gathers " and tends to settle freely. The amount of water necessary to produce this effect varies from a negligible quantity to 1 per cent or slightly more, by volume, of the charge. An excess causes sludge to solidify from the more viscous stocks, rendering the removal from the agitator exceedingly difficult. The treatment of lubricating oil requires skill and experience of the highest order. The slightest excess of acid at this point, over and above that required to produce the desired color, is further apt to sulphonate the heavier stocks, resulting in an emulsion in the transfer agitator that is exceedingly difficult to separate, although the introduction of the centrifuge has helped in a measure to solve such problems. The treated lubricating stocks are carefully transferred to lead-lined " wash " agitators, care being taken to avoid transfer of any sludge particles, which might cause emulsification. Some refiners neutralize during transfer, others dilute with hot water immediately, and still others only after neutralization is effected. Absence of acid is determined by the reaction to phenolphthalein solution, which turns a deep carmine in the presence of free alkali. Neutralization usually requires from twenty to forty-five minutes; as it progresses, the temperature of the batch is increased, commonly to about 160° F. Then it is allowed to settle over night; during this time, if treating has been properly conducted, the alkaline wash water will have settled as an opalescent milk, leaving the oil hazy bright. The last operation consists in blowing air through the heated oil until all moisture is removed. This operation is conducted either in the wash agitator or in special open-top bleachers, designed for this purpose. The older, slower method of brightening under glass-covered bleachers has become practically superseded by the quicker air-blowing process. Instead of caustic alkali or soda ash as a neutralizing agent, ammonium hydrate (ammonia water) has been used with more or less success, but apparently without advantages proportional to the increased cost of its application. As a general rule, the treatment of paraffin oils to marketable colors is easier than the securing of similar results with neutral stocks, time and treating losses considered, so that many pale neutrals and viscous red oils are treated with a minimum quantity of acid and finished by filtering. In short they are to all intents and purposes the equivalent of strictly filtered oils.

Tar treating, while formerly practiced to a considerable extent before the general advent of tower stills, is now practically obsolete. When employed, treating was customarily effected at 270° F., one-third of a pound of partially restored, 50° to 52° sulphuric acid per barrel being used. This resulted in a loss of from 4 to 5 per cent, and carried down sediment and impurities likely to precipitate in the tar stills to the great detriment of their bottoms. The sludge produced was allowed to settle in the treating agitator, forming a dense mass known as acid coke,[1] which was removed, after

[1] Notwithstanding the rather high percentage of sulphuric acid remaining in this substance, acid coke possesses a high heating value, containing, besides free carbon and heavy unsaturated bodies of high molecular weight, 14 per cent of liquid tar. A typical analysis follows:

	Per cent
Oil (tar)	13.67
Volatile carbonaceous material	19.18
Fixed carbon	37.75
Sulphur (free)	0.80
Sulphuric acid (48.6° Bé.)	28.25
Ash	0.35
	100.00 per cent
Fuel value	10,004 B.t.u. per pound

twenty-four hours' settling, by steel spuds. The coke was dropped through a trap door, at the apex of the agitator cone, into carts which carried this product to stills where it was commonly mixed with coal and burned as fuel. Neutralization of the treated tar was unnecessary, as the weak acid settled clear without entrainment. Tar and residuum from Gulf Coast crudes, intended for further refining into heavy lubricants and black oils, are treated at as high a temperature as 290° F., with from 10 to 15 pounds of 66° acid to the barrel. Such treatments require neutralization before additional refining can take place.

Paraffin "slack"[1] wax is also occasionally acid-treated. Formerly[2] all raw lubricating distillates were similarly treated. From 3 to 4 pounds of 66° sulphuric acid to the barrel were employed at a temperature of from 120 to 130° F. according to the melting point of the wax. "Sweated scale"[3] wax is also sometimes treated in small batches with finely divided bone or blood char, in lieu of filtration.

Lime, potassium permanganate, chromic acid, silicate of soda, etc., have been advocated and used at various times for special purposes, as have also certain proprietary compounds for breaking emulsions; but after many years of development, sulphuric acid, litharge, and caustic soda still form the bulk of treating chemicals used by the refiner.

As to operating labor, one treater with one or more helpers can usually look after all of the treating, although in the larger plants light oil and lubricating treating are commonly handled independently. With the laboratory control exercised by most refineries the mystery of treating is largely a thing of the past, although in handling lubricants, especially heavy viscous reds and neutral stocks, the personal equation of the treater has much to do with the success of chemical control, for exact duplication of laboratory conditions are frequently impossible to attain, and personal judgment must be exercised.

COLD-PRESSING

Cold-pressing, or simply "pressing," as it is often termed, may be defined in connection with refinery operations, as the separation by filtration of a solid petroleum product from a liquid petroleum medium in a standard type of filter press. The term pressing in its usual application refers to the separation of paraffin wax from some form of lubricating distillate, and will be used thus in this chapter unless the contrary is stated.

Ordinarily, the distillate to be cold-pressed is chilled to 5° to 10° F. in some form of standard chilling machine.[4] Brine is commonly employed as the refrigerating carrier, although direct expansion of ammonia is practiced in many plants. Chilling is frequently conducted in two stages of which the first is cooling from about 120°, at which temperature the wax-oil tank is usually kept to secure complete separation of moisture, to about 90°, by the aid of the cold-pressed oil in a counter-current apparatus. This may consist simply of a long tank, containing coils through which the cold-pressed oil is continuously pumped in an opposite direction to the surrounding wax oil, or more

[1] The term "slack" wax is applied to the soft wax obtained from the hot or cold pressing of paraffin distillate or wax oil. There is no differentiation on account of the base, although the pressed distillates themselves are generally separately refined.

[2] The treating of paraffin distillate with a small quantity of 66° acid is still practiced in many refineries. It is held that a better paraffin wax is produced thereby, and less acid is required to finish the reduced lubricating oils; consequently there is not so much danger of over-treating and its attendant evil of emulsification. Other refiners maintain that the treating of paraffin distillate is a waste of acid, considering that from 30 to 50 per cent of its composition is gas-oil. They claim to produce wax and finished oils of superior quality by close attention to sweating and final treatments.

[3] The name "scale" wax is applied to the crude gray or nearly white oil- and moisture-free wax coming from the sweaters before final filtration or resweating, for semi-refined or refined grades.

[4] For a description of the mechanism and appearance of various types of chilling machines, see p. 194 and Figs. 80, 81 and 82.

preferably of a few chilling machine sections, the cold oil taking the place of brine or ammonia. With very rich wax distillates, pressing may take place after such preliminary cooling, the operation being known as hot pressing; but in ordinary practice the distillate is further cooled to the temperature previously mentioned [1] before being pumped to the presses,[2] which in the meantime have been set up at 700 pounds pressure. The whole operation is rendered continuous, as far as possible, by the employment of several presses, so that one or more may be charging while others are being taken down or set up for a new cycle. Some plants employ a large-volume, low-pressure pump to fill the press up to the point where pressure develops, after which charging is usually effected by triplex or three-throw pumps, while in others the triplex pumps are used from the start. Pressure usually begins to build up after ten to fourteen hours of pressing. With a properly "cracked" crystalline distillate, a maximum of 350 to 450 pounds is developed in twenty-four to thirty-six hours; the press is then full and ready to take down, after pressure has been maintained for several additional hours so that the wax cake will be as dry as possible. In the meantime, the flow of chilled paraffin distillate or wax oil has been diverted to an empty press so that the continuity of operation will not be interrupted.

In taking down a press, a reversal of the procedure of setting up is employed: sufficient pressure is put on the ram to force the platen head up on the supporting rods, so that the nuts on the tension rods may be loosened and removed; the flow in the ram is then reversed and the platen head is drawn away from the press plates to the extent of the ram travel. The trough, which has been in position under the apron at the press to receive the pressed oil, is now made to recede under the platform, exposing the screw or endless carrier which is set in motion in readiness to handle the solid slack wax. The latter is removed from the rings and plates by the aid of spud bars, two operatives, one working on each side of the press, effecting such removal. As fast as the plates and rings are cleaned, they are moved up toward the ram end of the press, each plate being taken in rotation until the entire press is clean. The entire operation of stripping a 400 by 48-inch plate press of half-inch rings does not usually require over three hours, provided the wax is of a good crystalline quality. While claims are made that viscous distillates, containing more or less amorphous wax, can be successfully pressed through wool blankets of special design, the majority of refiners find it more advantageous to use the standard 12-ounce duck-covered plates and to operate on crystalline wax oil or paraffin distillate. The course of the pressed distillate has already been discussed in the section on fractionation methods.[3] The slack wax is now washed or treated, according to preference; in many plants it is charged directly to the sweaters.[4]

Fractional Fusion

Fractional fusion, or "sweating," as it is termed in refinery parlance, may be defined as the separation of liquid and amorphous wax from solid crystalline paraffin by the gradual application of heat. In the practical operation of the process, the melted slack wax is commonly floated on water, level with the sweating screens, and is next chilled to solidification by cold water which is pumped through the coils with which each pan is equipped. The water below the wax is then with-

[1] Wax-oil or paraffin distillate is commonly pressed at a temperature that will insure the finished reduced neutral or paraffin stocks standing 25° to 30° cold test. A pressing temperature of 5° to 10° usually secures this result. Where zero cold-test oils are demanded, a second pressing at minus 10° F., or lower, is commonly practiced.

[2] Various types of filter presses are illustrated in Figs. 86 and 87.

[3] See p. 356.

[4] For a description of various types of sweaters see p. 199; Fig. 88, p. 200, gives an excellent idea of a type of pan in wide use.

drawn, leaving a cake of solid wax, 4 to 6 inches in thickness, resting on the screen. The apparatus is now in readiness for sweating. Two methods are in common use, one in which the temperature of the sweating ovens is gradually raised at the rate of 1 to 2° per hour; and one in which water is circulated through the above-mentioned coils in gradually increasing temperature. Quite frequently both methods are used in conjunction, this course securing a very even sweating, when temperatures are properly controlled. Various regulating devices to secure a uniform rise in temperature are offered on the market, that of C. J. Tagliabue[1] being quite commonly employed. The cuts employed in sweating slack wax are dependent on the nature of the product, the percentage of oil and the desired objective in melting point. The following schedule gives an idea of the cuts used in a large Mid-Continent refinery manufacturing 124° to 126° F. semi-refined paraffin wax as its principal wax product, and 108° to 110° and 120° to 122° semi-refined waxes as by-products.

Typical Cuts in Sweating Slack Wax

Cut	Name of product
Start = 80°	Wax oil
80–90	Light-foots oil*
90–115	Heavy-foots oil
115–off	Intermediate scale†
On screen	124°–126° crude scale wax‡

* "Foots" oil contains only low melting point wax of little market value, and yet is of too high a cold test, and of too low a viscosity for a lubricating product. It is a source of constant trouble to the refiner. It cracks to higher melting point waxes with difficulty, the cracked distillate retaining much of its amorphous quality, so that it can only be returned to the process in small admixtures, or chilling machines and presses will become clogged. The heavier "foots" can be successfully sweated, but as previously mentioned the operation is rarely a profitable one for the refiner.

† Intermediate "scale" wax, running from 115° to 117° F. in melting point, is usually resweated, using same cuts employed for slack wax. This produces a superior grade of 124° to 126° F. scale wax, containing less than 1 per cent of oil and moisture.

‡ Crude scale wax of 124° to 126° melting point is usually sold with a guarantee of less than 2 per cent oil and moisture, much of the filtered scale of semi-refined wax running, however, less than 1 per cent of these impurities. Large quantities of 120° to 122°, 124° to 126° and 126° to 128° semi-refined paraffin wax are used in candle manufacture, water-proofing, electrical insulating compounds, miners' lights, and in scores of proprietary floor dressings, furniture polishes, etc.

Typical Cuts in Sweating Heavy Foots Oil

Cut	Name of product
Start = 80°	Wax oil
80–90	Light-foots oil
90–106	Heavy-foots oil
106–off	108°–110° crude scale wax
On screen	120°–122° crude scale wax

In general, second and third sweatings require a much longer time to effect separation because the intermediates are more uniform in composition. The manufacture of the lower melting points is a particularly tedious operation, and is not often justified by the price obtained. Therefore many plants offer only the higher melting point grades, recracking and processing waxes of low melting point.

While waxes of higher melting points than 126° to 128° can be obtained by primary sweating of hard-pressed wax,[2] or by resweating methods, as a rule they cannot be

[1] In the latest form of Tagliabue temperature-control apparatus, a progressive rise in temperature of 2° F. per hour may be obtained, or the apparatus may be set to maintain a constant temperature as may be desired.

[2] Before the general advent of the modern sweater, it was customary to subject the slack wax enfolded in canvas cloths with wooden separating frames between, to a pressure of 200 pounds per

economically produced from wax oil or other steam-run products of second distillation. Once-run paraffin tower distillate usually furnishes the waxes of higher melting point. Refined paraffin wax is obtained by resweating scale wax to nearly complete absence of oil and moisture, followed by special purification methods; whether obtained from paraffin distillate or wax oil it is identical in composition [1] when of the same melting point.

In transporting paraffin wax between refinery points and export centers, tank cars are frequently used, but when prepared for the trade, wax is invariably packed in "slack barrels"[2] or burlap-protected paper sacks, or it is molded into cakes of various sizes. When packed in bulk in barrels or sacks, a chipping machine, illustrated in Fig. 111, page 220, is employed. In the operation of this apparatus, a slowly revolving hollow cylindrical drum, usually about 36 inches in diameter by 4 to 6 feet long, dips into a constant level bath of wax maintained at about 140° F. A continuously circulating stream of cold water or brine passing through the drum chills the film of wax deposited during immersion. This film, in three-quarters of a rotation, is sufficiently solid to be scraped off in a flexible sheet approximately $\frac{1}{16}$-inch in thickness, by means of a knife pressing against the face of the drum. The semi-solid wax thus obtained is easily packed in barrels or sacks, slowly solidifying to a dense compact mass.

When wax is prepared in cake form, the Gray wax-molding press [3] is commonly employed. This is made up under 500 pounds pressure with alternate molds and plates, in a somewhat similar manner to the standard filter press, the plates being locked in position by means of a split collar placed over a supporting rod behind the head, and secured by a tapered key. The hose inlet and outlet connections having been made, the press is ready for operation. Cooling water is now turned on, the wax valve opened, and the press filled as rapidly as possible. Care must be taken to have enough wax in the reserved space to allow for shrinkage, experience guiding the operator in this matter. When sufficient molten wax is in the press to insure perfect cakes, the hot plate is placed in position, this being necessary in order to keep the wax warm as it sets in the molds, and also to prevent the surplus from clinging to the top of the press when the cakes have become chilled. The operation of molding is usually complete in two to three and a half hours after the press is filled, and the cakes are then ready for

square inch at about 70° F. in a standard type of hydraulic press. A crude form of sweating then followed, producing a high melting point wax, but naturally low in yield; about 9 per cent on a 10½-per cent tar. Hydraulic pressing in conjunction with modern sweating is still used in certain refineries where special objectives are desired.

[1] Refined paraffin wax is pure white, the better grades being of 25 color in melted condition and showing in solid state a translucent rather than an opaque whiteness. It is also practically odorless and tasteless, containing usually less than 0.5 per cent of oil and moisture. It is used in enormous quantities for impregnating waxed papers, laundering, protecting cheeses and preserves from putrefaction and fermentation, and also for general domestic purposes. The lower 108° to 110° melting point wax is exported in considerable quantities as match wax, and in its refined state forms the principal constituent of the modern protective wax dressing for burns. The U. S. Pharmacopœia describes it (paraffinum) as a colorless, more or less translucent mass, crystalline when separating from solution, without odor or taste, and slightly greasy to the touch, consisting of a mixture of solid hydrocarbons chiefly of the methane series; usually obtained by chilling and pressing the distillates from petroleum having high boiling points, and purifying the solid press cake so obtained. Its characteristics are given as follows: Specific gravity, 0.890–0.905 at 25° C. (77° F.); melting point, 51.6°–57.2° C. (125°–135° F.); insoluble in water or alcohol; slightly soluble in absolute alcohol; readily soluble in ether, petroleum benzine, benzol, carbon disulphide, volatile oils, and in warm fixed oils.

[2] While a considerable amount of wax is shipped in new flour barrels or second-hand sugar barrels, the greater quantity of package goods is handled in a specially made slack barrel usually containing 235–245 pounds net of wax, 19 to 20 pounds tare. Wax below 115° melting point must be shipped in tight cooperage.

[3] See p. 222 for a description of the mechanism of the Gray molding press. It is illustrated in Fig. 112, p. 221.

removal. The actual time required depends upon the temperature of the cooling liquid and the melting point of the wax employed. As soon as the cakes have become thoroughly chilled, the top plate is removed and the surplus wax detached. Sufficient pressure is applied to the ram to ease out the key, which is then removed; the ram is reversed in action, and the movable platen head drawn back. The finished wax cakes are then made accessible by pushing back the cooling plates. The wax thus molded has perfectly square edges and is of unvarying thickness, allowing 260 pounds of finished wax to be packed in a case 37 inches long by 19½ inches wide and 12 inches deep, compared with 216 pounds of pan-molded wax. The cakes produced by the latter method are beveled on the four edges and hollow at the top.

In the larger plants, the wax plant is usually operated by a chief engineer aided by three shift engineers or "runners." In plants of moderate or smaller size the chief engineer or wax plant foreman serves as day engineer, only the night runners alternating. A helper is usually employed on each shift, and frequently looks after the sweating as well. The schedule of operation is usually planned so that presses will come down in the day shift. The stripping and setting up of the presses is commonly handled by operatives detailed for this purpose. Wax filtration, barreling, or cake forming is handled in some refineries in connection with the wax plant, and in others falls under the jurisdiction of the filtering and barreling departments.

Cold-settling

Cold-settling may be defined in refinery practice as the separation, by virtue of difference in specific gravity, of a petroleum product, solid at the temperature employed, from an enveloping liquid petroleum medium. In its usual application, the term refers to the separation of amorphous wax at low temperatures from a naphtha solution of filtered steam-refined stock.[1]

In the actual operation of the process, the stock to be cold-settled—either a stock which has been previously filtered and mixed with naphtha, or preferably the resultant filtration product of a naphtha steam-refined stock "mix"—is slowly cooled until the amorphous wax settles to the bottom of the precipitation tanks. The latter are heavily insulated and usually of cylindrical vertical form, provided with conical bottoms and suitable cooling coils. The percentage and gravity of the naphtha used is of great importance, as is also its volatility, different stocks requiring different mixes according to their individual composition and wax content, this in turn effects the settling period and the precipitation temperature necessary to attain the desired objective. A 60 per cent mix of 52° gravity,400° F. end-point naphtha, with the gradual chilling of the mixture to 10° F. in four days' time, is used by a large Mid-Continent refinery with complete success. No hard-and-fast rule is applicable, however; the operation of cold-settling, while simplicity itself in theory, requires much attention to technical detail in practice, to secure bright stocks of low cold test and freedom from cloud.

In completing the cycle of operations in the cold-settling process, the wax-free naphtha solution of stock is brought to test in a standard form of reducing still, the naphtha being returned to the process, and the stock pumped to storage or further filtered as desired. The amorphous wax, when naphtha-free, is sold as petrolatum grease, or is filtered directly or in conjunction with other suitable bases for finished petrolatum. A modification of the cold-settling method, in which the precipitated amorphous wax is centrifuged from the liquid medium without requiring settling, is

[1] Cold-settling is also practiced with some degree of success in lowering the cold test of straight steam-refined stocks, particularly of such grades as are produced from the Wyoming crudes.

the Sharples Process [1] which has recently been installed in several refineries operating in different sections of the country.[2]

Both the older and the Sharples systems commonly employ tanks provided with coils to obtain the desired refrigeration, using brine as a medium of heat interchange; but the use of standard chilling machines employing direct ammonia expansion is practiced with success in a few refineries. In general, the labor requirements of a cold-settling plant are small, apart from the initial filtration of the stocks and the subsequent reducing of naphtha solutions; nevertheless, constant attention is required and where a plant of this kind is installed it is usually under a separate department, although occasionally under the jurisdiction of the wax-plant foreman.

Decolorization

Decolorization, apart from chemical treatment, i.e., decolorization by adsorption, or " filtering," as it is termed in refinery parlance, may be defined as the art of separating solid suspended, colloidal, and dissolved impurities [3] from liquid petroleum products by passage through dense layers of decolorizing materials.[4] While burning-oil and even crude is occasionally thus processed, filtering is generally restricted to amorphous and paraffin waxes, neutral and steam-refined stocks; removal of suspended carbon, tarry matters, etc., with incidental improvement in color, are the chief objectives.

As commonly practiced in modern refineries, filtering is effected in cylindrical vertical tanks of small diameter, known as filters. The mechanism of these has already been described and specifications for them have been given.[5] The product to be filtered usually passes through 10 to 20 feet of filtering material, according to the length of filter employed, nature of oil to be filtered, and degree of purity or color desired. In general, the greater the depth of filtering material, the more improvement in color. But when the speed of flow is so retarded by the presence of large amounts of suspended or tarry impurities, or by reason of the high viscosity of the oil itself, that the issuing stream is practically negligible in quantity, shorter filters must be employed. Both hot and cold filtering are practiced, the former with paraffin wax and highly viscous steam-refined stocks, the latter with neutrals, red oils, and naphtha stock solutions; cold filtering is always the more desirable on account of the better colors obtained, and the saving of fuel.

[1] For a complete description of the Sharples Process see chapter on Special Refining Processes, p. 389.

[2] Refineries that have lately installed the Sharples Process are the Kendall Refining Company, Bradford, Pa.; Marland Refining Company, Ponca City, Oklahoma; and Mid-West Refining Company, Casper, Wyoming.

[3] Small particles of coke, finely divided and colloidal carbon, tarry complexes, of high molecular weight, floc, certain sulphonates, dissolved coloring matter, traces of suspended alkali and moisture, are all removed to a greater or less extent during the process of filtration. As carried out in petroleum refineries, this process is really a combination of simple filtration, decolorizing and deodorizing.

[4] Of the materials employed in clarifying petroleum products by filtration, only two, bone char and fuller's earth, have stood the test of time. The latter is by far the more commonly employed. The product first named is obtained by destructive distillation of the bones of domestic animals while the second product is mined in vast quantities in Florida, Georgia, Texas and California. Both substances are offered to the trade in various degrees of fineness, from a coarse 16–20 mesh to a fine flour. The analysis of a typical fuller's earth was found to be as follows: Hygroscopic water, 42.00; water of combination, 7.52; silica, 32.78; aluminum oxide, 9.58; ferric oxide, 2.30; calcium oxide, 1.15; magnesium oxide, 4.57; sulphuric anhydride, 0.10 per cent. When fuller's earth is prepared for the trade, the greater part of the hygroscopic water is removed, but chemical analyses should not be depended upon to establish decolorizing power; this factor being readily determined by comparison with an earth of known value in a small laboratory filter.

[5] See pp. 65 and 201; also Fig. 89.

Before being used for filtering, new earth must be " tempered," i.e., dried at a temperature sufficient to remove all of its hygroscopic moisture and most of its water of crystallisation, although it is undesirable to overheat to such an extent as to completely volatilize the last traces of moisture. Different earths require different temperatures, ranging from 500° to 900° F., for removal of their combined water of hydration, this process being effected in a vertical or rotating kiln, described and illustrated in an earlier section.[1] However, not so much dependence is placed on temperature by most refiners, as on the color of the earth, which gradually changes from gray or red [2] to a grayish-blue shade as dehydration progresses, the preferred color having been determined beforehand by comparative filtrations with samples ignited to varying degrees of grayness.

Not only do different petroleum products require earths of various original ignition temperatures to secure the best results, but the size of the grain is also of the utmost importance. In general, light oils require a less ignited and finer grain for filtration than do heavy viscous neutrals and steam-refined stocks. A 30 to 60-mesh earth is preferred by many refiners for neutral and petrolatum filtration, while a 16 to 30 grade gives the best satisfaction with viscous steam-refined stocks, of 100 to 160 at 212 viscosity, filtered generally at 130° to 160° F.

With a view to the more intelligent selection and treatment of fuller's earth in its original ignition and subsequent revivification, the theories regarding its action in filtration become of interest. The statement of Parsons,[3] that the water of composition is not an essential factor in the bleaching power of all fuller's earths, and that some decolorise equally well before and after the removal of the water, while others lose a considerable part of their bleaching effect when their water is evaporated, has been found by the writer to be largely correct with many, though not with all oils. Gilpin and Schneeberger [4] regard fuller's earth as a dialyzing septum and petroleum as an emulsoid, dialysis allowing the free passage of paraffins, and causing the coagulation and absorption of the bitumens, such action also causing entrainment of the sulphur and nitrogen compounds, as well as the olefines present. As an interesting commentary on this supposition it should be noted that a process has been recently proposed to remove asphalt from cylinder stock by heating the same with finely divided fuller's earth, and then regenerate the pure bitumen by washing the absorbent material with benzol. The writer has also secured a reduction in combined sulphur (sulphonic) content in burning-oil distillate from .015 to .004 per cent by passage through fuller's earth. The opinion of Gurwitsch [5] that polymerization of unsaturated compounds is effected by passage through Florida fuller's earth seems to be borne out by his experiments. The formation of the foul-smelling, complex nitrogenous compounds produced during the filtration of sweet petrolatum stock through fuller's earth, and absent in bone-char filtration, could be thus explained. Löb [6] considers the bleaching action of filtration to be due to the presence of some substance in the fuller's earth that enters into combi-

[1] See Figs. 93, 94, 95 and 96.

[2] The fuller's earth produced in Florida, comprising by far the greater amount used in the petroleum industry, as sold by one of the largest producing companies, is of a grayish-white color; another grade produced in large quantities has a distinct reddish-yellow cast, becoming grayish-blue in burning. Both grades are considered efficient decolorisers.

[3] Bureau of Mines, Bull. 71, p. 6.

[4] Am. Chem. Jour., 50, 59.

[5] In "Wissenschaftliche Grundlagen der Erdölbearbeitung," 231, 1913, Gurwitsch states that when a fuller's earth residue, used for decolorising petroleum, is extracted with ether or benzol, and the solvent is distilled off and the residue mixed with the original oil, the combined product has a much darker color than it possessed before filtration; this phenomenon is ascribed by the author to polymerisation by the earth of the unsaturated compounds of the oil.

[6] Chem. Rev., 15 (1908), 80.

nation with the coloring matter of the oil, forming an insoluble compound; while Gräfe [1] regards decolorization as a physical and not a chemical process. See also Adsorption, pages 534 and 745, volume I.

After filtering has proceeded until the issuing stream is no longer of marketable color, charging of the filter is stopped and the latter is allowed to drain, unless it be desired to strain an additional quantity of oil for subsequent refiltration. In this case the operation is continued until the desired quantity of oil has accumulated.

After draining has continued from six to twelve hours, according to the viscosity of the charge and the temperature employed during filtration, a wash of hot benzine or naphtha [2] is employed. After this has stood long enough to thoroughly soak up the earth, it is steamed off, and followed by a second wash, and a third if necessary. A practically colorless effluent signifies that the washing process is complete. The early system of filtration through a series of small filters with transfer of the unwashed earth or bone char to a large "wash" filter is practically obsolete; filtering and washing in the same filter without transfer has been found to be more economical. A variation in filtration method, is to thoroughly incorporate the distillate or stock to be filtered with varying amounts of fuller's earth and then filter-press the mixture; but on account of the large amount of oil remaining in the press there seems little likelihood of such a method becoming generally adopted.

After being properly washed, the earth or bone char is now ready for revivification, this being accomplished at a low red heat. Sufficient combustible material, insoluble in the naphtha wash, usually remains in the pores of the earth to materially cut down the amount of fuel necessary to burn to the proper temperature, which for the first burning should be about 1100° F. While it is claimed that bone char is successfully revivified, without undue loss, in an open type of furnace under a reducing atmosphere, the high cost of this material favors the closed-retort type of apparatus, such as that of Ebey or Kent, from which air is completely excluded, preventing the formation of bone ash of low filtering power. No special precautions are necessary, however, in the burning of fuller's earth, other than avoiding temperatures that will cause sintering and closing of the pores. This material, with its high filtering power and comparative cheapness, is therefore ideally suited for refinery use, and has replaced bone char to a very considerable extent.[3]

The results obtained in filtration, and the time consumed in the operations incident thereto, vary considerably among the different refineries, for reasons previously enumerated. The following schedules will, however, give a fair idea of the results obtained for typical oils in Pennsylvania and Mid-Continent practice.

[1] Petroleum, 3 (1907), 292.

[2] Some refiners use a light non-viscous stock for the first and second washes, following with naphtha as a final solvent.

[3] While fuller's earth has practically replaced bone char as a decolorizer, the latter must be used where deodorizing action is required, and therefore is still employed in the manufacture of petrolatum. Bone char in its spent condition finds a sale as a fertilizer and phosphate base, and when saturated with heavy oil is sold for case hardening purposes. Blood char, occasionally used for bleaching paraffin wax, is very apt to impart sulphur compounds to the latter and these compounds, though colorless and odorless, exert a blackening action on silver and copper, causing general complaint from the trade.

Typical Yield, Filtering 600° F., Steam-refined Stock

(Pennsylvania practice)

(Size of filter, 5 feet diameter by 10 feet high; filtering material, 5200 pounds, once burned, 16–30-mesh fuller's earth; filtering temperature 140° F.)

Charge:	5149 gallons	
Yield:	973 gallons	D 600° F. filtered stock
	2730 "	E 600° F. filtered stock
	534 "	Drips *
Filtering time:		48 hours 30 minutes

* This product, too dark to be included in E stock, represents the drainings of the filter, and is set aside for charging the next filter in succession. It will be noted that a discrepancy of 912 gallons exists between total yield and charge; this amount is retained by the earth, and in the case of Pennsylvania stock will be largely recoverable in the naphtha wash.

Typical Yield, Filtering 115° M.P. Petrolatum Stock

(Pennsylvania practice)

(Size of filter, 5 feet diameter by 10 feet high; filtering material, 7200 pounds fresh, 30–60-mesh bone char; filtering temperature 125° F.)

Charge	3300 gallons
Yield:	
Snow-white petrolatum *	281 gallons
Lily-white petrolatum	259 "
Cream-white petrolatum	212 "
Extra light amber † petrolatum	537 "
Light amber	1130 "
Drips ‡	343 "
Filtering time	24 hours 15 minutes

* The white petrolatum, or petrolatum album of the U. S. Pharmacopœia, defined as a colorless mixture of hydrocarbons, chiefly of the methane series, obtained by distilling off the lighter and more volatile portions from petroleum and purifying the residue. A white unctuous mass, of about the consistency of an ointment, transparent in thin layers, completely amorphous, without odor or taste. In other respects white petrolatum has the characteristics of ordinary petrolatum and should respond to the tests given that substance.

† This and the grade following are equivalent to a greater or less degree to the multiplicity of preparations sold as Soft Paraffin, Petroleum Jelly, Paraffin Jelly, "Cosmoline," "Vaseline," Unguentum Petrolei, etc. As produced from Pennsylvania products, the amber grades of petrolatum contain hydrocarbons from $C_{16}H_{34}$ up to probably $C_{32}H_{66}$, and also contain members of the higher olefine series, such as $C_{15}H_{32}$, $C_{17}H_{34}$, etc.; they conform in all respects to the tests prescribed for petrolatum in the U. S. Pharmacopœia. Petrolatum is insoluble in water, scarcely soluble in cold or hot alcohol, or in cold absolute alcohol, but soluble in boiling absolute alcohol, and readily soluble in ether, chloroform, carbon disulphide, oil of turpentine, petroleum benzine, benzene, and fixed or volatile oils.

‡ Petrolatum drips and other dark grades find a limited sale as veterinary salves, shoe blacking pastes, greases, etc., but these articles can generally be made more profitably from the darker grades of petrolatum stock than from a stock suitable for the manufacture of pharmaceutical goods. The drips from the typical filtration listed above would commonly be set aside for refiltration into white goods.

Typical Yield, Filtering Neutral Stock of 240 Viscosity at 100; 410° Flash

(Mid-Continent practice)

(Size of filter, 8 feet diameter by 20 feet high; filtering material fresh 16–60 fuller's earth; filtering temperature 120° F.)

Charge:	345 barrels
Yield:	
No. 2 color, 190/100 viscosity pale viscous neutral...	15 barrels
No. 3 color, 200/100 viscosity pale viscous neutral...	40 "
No. 4 color, 220/100 viscosity viscous neutral.......	70 "
No. 5 color, 240/100 viscosity viscous red oil........	140 "
Drips.................	35 "

Filtering time: 96 hours

The drop in viscosity, with improvement in color, is particularly noticeable with oils of this type, the difference being more pronounced with certain Gulf Coast lubricants; but such classes of oils, when finished to three color or better, are exceptionally low in carbon, as the following schedule will indicate:

Pale Oils

Source of crude	Type of oil	(°Bé.) gravity	Flash, degrees F.	Fire, degrees F.	Viscosity per 100	C.T.	Color	Carbon, per cent
Pennsylvania	Filtered neutral............	30.5	405	465	180	32	3	0.42
Ohio........	Treated paraffin............	24.5	390	450	175	30	3	0.76
Ohio........	Treated and filtered paraffin..	24.7	390	450	170	30	3	0.47
Mid-Cont...	Treated and filtered neutral..	26.5	405	465	200	32	3	0.40
Texas.......	Treated and filtered neutral..	20.0	325	370	190	5	3	0.26
California...	Treated neutral............	21.5	325	385	175	0	3	0.48
California...	Treated and filtered neutral..	21.7	325	365	170	0	3	0.24
Russia......	Filtered neutral............	27.0	370	435	228	−0	1	0.10

Red Oils

Source of crude	Type of oil	(°Bé.) gravity	Flash, degrees F.	Fire, degrees F.	Viscosity per 100	C.T.	Color	Carbon, per cent
Pennsylvania	Filtered neutral............	29.1°	445	405	260	33	5	0.52
Ohio........	Treated red paraffin.........	23.3	415	465	240	31	5	0.98
Mid-Cont...	Treated and filtered red neutral.....................	25.5	390	445	250	25	5	0.55
Texas.......	Treated neutral............	20.0	345	390	330	0	5	0.35
California...	Treated and filtered........	23.1	355	415	300	0	5	0.30

The time consumed in washing and emptying a filter will depend upon the nature of the oil filtered, the extent of draining, the size of grain of filtering material, the temperature of the washing medium, and to a great extent, upon the type of mechanical equipment installed for handling the washed and steamed charge. A filter of the largest size mentioned should not require more than six or eight hours for three successive washings and steamings of naphtha, and with modern conveying equipment should be emptied and ready to be packed again five or six hours later. Some refiners consider that the greatest profit is found in refiltering to light colors only, while others allow

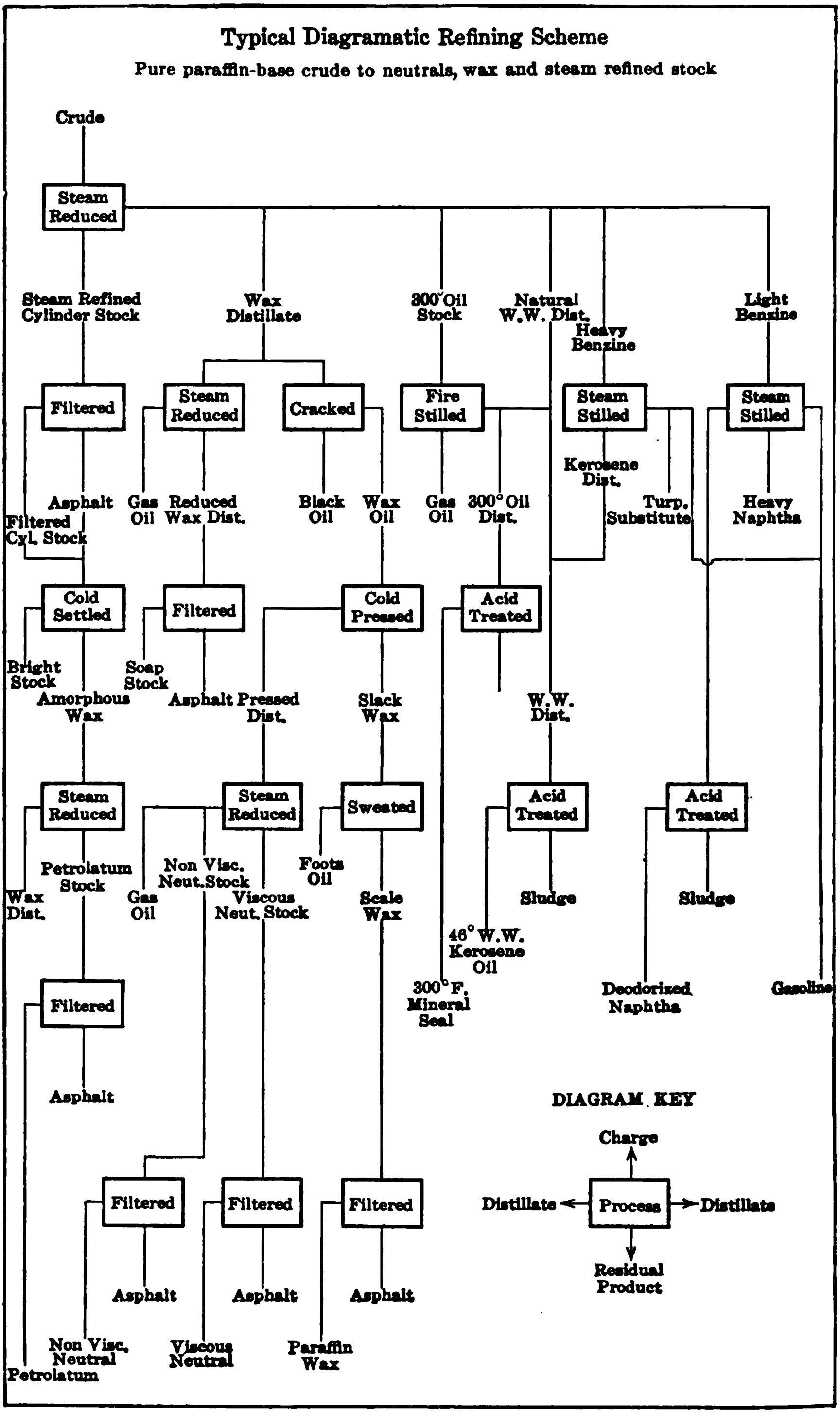

Typical Diagramatic Refining Scheme
Pure paraffin-base crude to neutrals, wax and steam refined stock
Crude
Steam Reduced
Steam Refined Cylinder Stock
Wax Distillate
300° Oil Stock
Natural W.W. Dist.
Heavy Benzine
Light Benzine
Filtered
Steam Reduced
Cracked
Fire Stilled
Steam Stilled
Steam Stilled
Asphalt
Filtered Cyl. Stock
Gas Oil
Reduced Wax Dist.
Black Oil
Wax Oil
Gas Oil
300° Oil Dist.
Kerosene Dist.
Turp. Substitute
Heavy Naphtha
Cold Settled
Filtered
Cold Pressed
Acid Treated
Bright Stock
Soap Stock
Amorphous Wax
Asphalt
Pressed Dist.
Slack Wax
W.W. Dist.
Steam Reduced
Steam Reduced
Sweated
Acid Treated
Acid Treated
Petrolatum Stock
Wax Dist.
Gas Oil
Non Visc. Neut. Stock
Viscous Neut. Stock
Foots Oil
Scale Wax
Sludge
Sludge
46° W.W. Kerosene Oil
300° F. Mineral Seal
Deodorized Naphtha
Gasoline
Filtered
Asphalt
DIAGRAM KEY
Charge
Distillate
Process
Distillate
Residual Product
Filtered
Filtered
Filtered
Asphalt
Asphalt
Asphalt
Non Visc. Neutral
Petrolatum
Viscous Neutral
Paraffin Wax

Fig. 156.

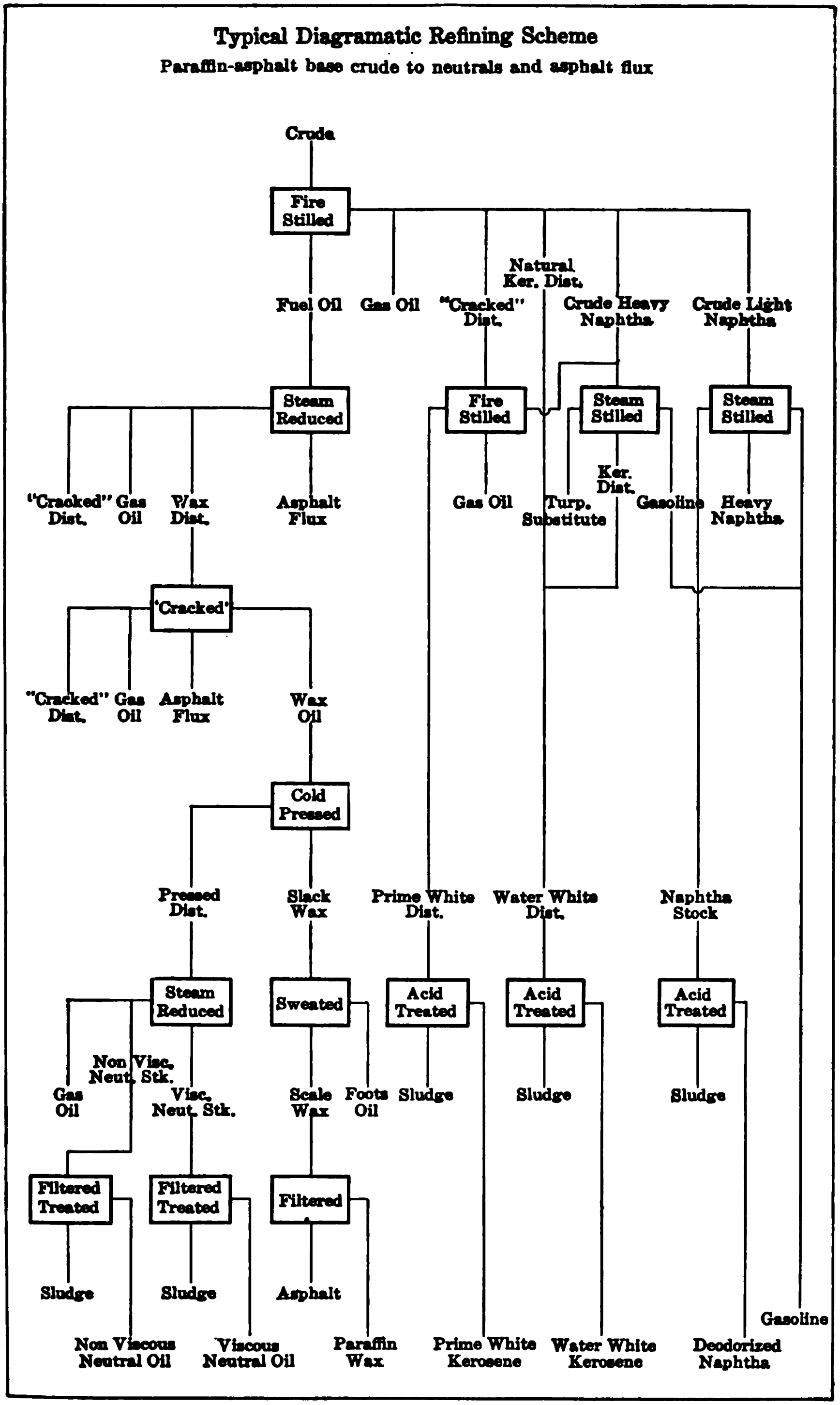
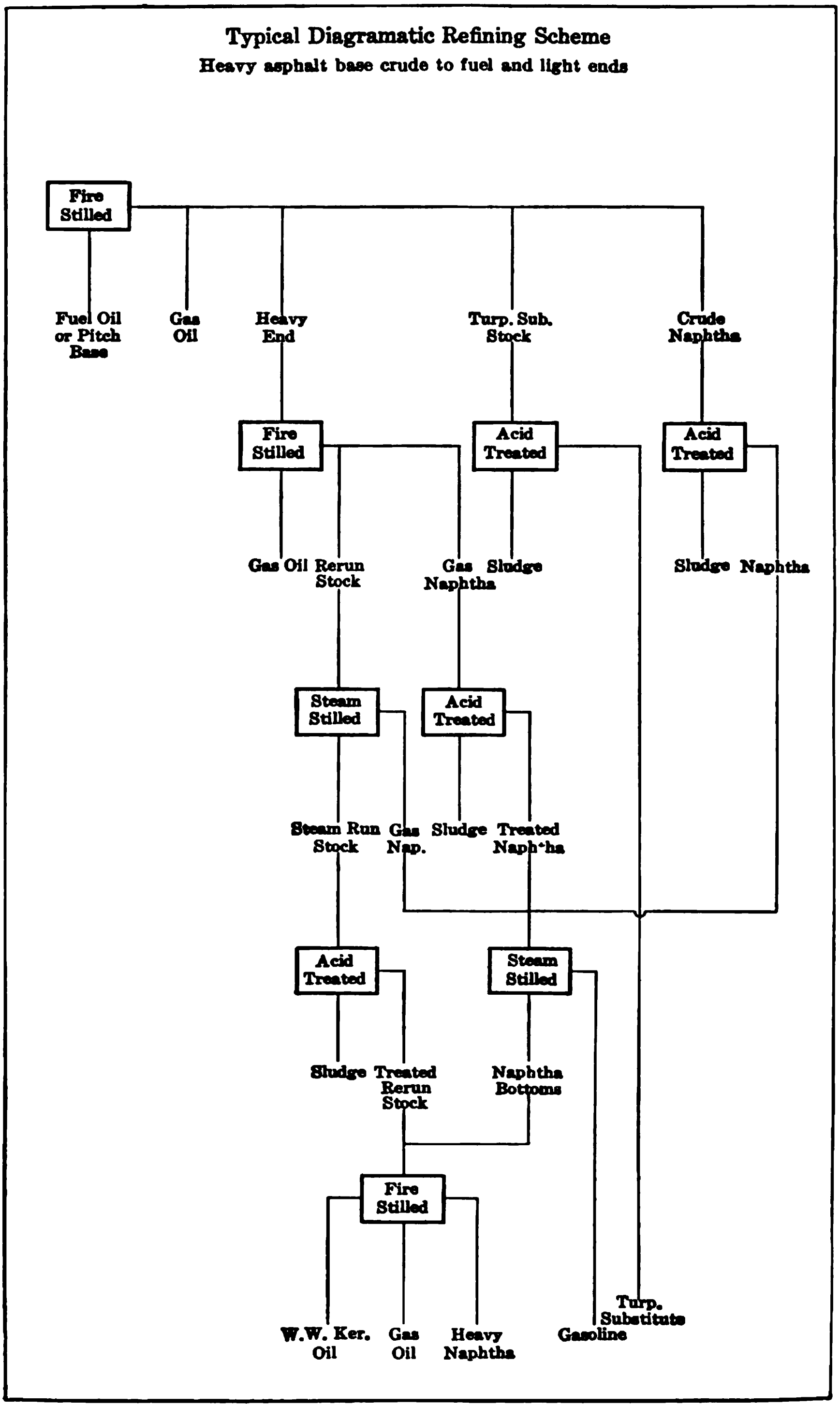

Typical Diagramatic Refining Scheme
Paraffin-asphalt base crude to neutrals and asphalt flux
Crude
Fire Stilled
Fuel Oil
Gas Oil
"Cracked" Dist.
Natural Ker. Dist.
Crude Heavy Naphtha
Crude Light Naphtha
Steam Reduced
Fire Stilled
Steam Stilled
Steam Stilled
"Cracked" Dist.
Gas Oil
Wax Dist.
Asphalt Flux
Gas Oil
Ker. Dist.
Turp. Substitute
Gasoline
Heavy Naphtha
'Cracked'
"Cracked" Dist.
Gas Oil
Asphalt Flux
Wax Oil
Cold Pressed
Pressed Dist.
Slack Wax
Prime White Dist.
Water White Dist.
Naphtha Stock
Steam Reduced
Sweated
Acid Treated
Acid Treated
Acid Treated
Gas Oil
Non Visc. Neut. Stk.
Visc. Neut. Stk.
Scale Wax
Foots Oil
Sludge
Sludge
Sludge
Filtered Treated
Filtered Treated
Filtered
Sludge
Sludge
Asphalt
Gasoline
Non Viscous Neutral Oil
Viscous Neutral Oil
Paraffin Wax
Prime White Kerosene
Water White Kerosene
Deodorized Naphtha

FIG. 157.



Typical Diagramatic Refining Scheme
Heavy asphalt base crude to fuel and light ends
Fire Stilled
Fuel Oil or Pitch Base
Gas Oil
Heavy End
Turp. Sub. Stock
Crude Naphtha
Fire Stilled
Acid Treated
Acid Treated
Gas Oil
Rerun Stock
Gas Naphtha
Sludge
Sludge
Naphtha
Steam Stilled
Acid Treated
Steam Run Stock
Gas Nap.
Sludge
Treated Naph'ha
Acid Treated
Steam Stilled
Sludge
Treated Rerun Stock
Naphtha Bottoms
Fire Stilled
W.W. Ker. Oil
Gas Oil
Heavy Naphtha
Gasoline
Turp. Substitute

FIG. 158.

filters to make all possible marketable grades. The first method naturally returns a greater apparent profit, but it calls for frequent recharging of the earth; the second procedure, giving less profit per gallon, allows a greater quantity of raw material to be handled with the same amount of filtering material. It is obvious that local conditions, current market and prior contracts will govern the course adopted, this being an individual problem for each refinery. As to operation labor, filter-house and revivifying equipment is generally under the direction of the filter-house foreman. Where modern conveying equipment is installed, and a permanent distributing system for the filtered oils exists, one man in the filter house and one looking after the burning of the earth can usually attend from twelve to twenty filters, the number of operatives being increased in proportion to handling of filtering material required, shifting of flow, pumping-out lines, etc. Where filtering is effected under pressure, additional labor is usually required, as is also the case where the filter house is required to pump up its raw stocks for filtration.

Cracking

While ordinarily included under the head of general or special refining processes, cracking has become so important that it is discussed in this volume as a separate chapter.[1]

Flow Charts

As a general résumé, process or flow charts, showing products obtained and general refining steps involved for the more important crudes, are given on the pages immediately preceding. The data on general refining processes are thus condensed in tabular form (Fig. 156, 157 and 158).

III. SPECIAL REFINING PROCESSES

Any attempt to describe or cover even a small fraction of the many special refining methods which have been proposed, which are either in process of development or in actual use, is entirely beyond the scope of this volume. Aside from the fact that many of such processes are of doubtful ultimate practicality, others are carefully guarded secrets which for obvious reasons could not be discussed. Therefore only a few of the more important successful special processes, typical of some particular branch of the industry are included, the Simplex Refining Process[2] being selected, not only as representing primary fractional distillation, but as giving an excellent idea of the refining steps involved in handling a considerable portion of the California product.

The Simplex Refining Process

This process, which was originally intended merely as a continuous topping system, has been so improved that it is now a highly efficient method for the fractionation of almost any type of crude.[3] The salient features of the process are:

1. Continuous operation.
2. Large capacity.
3. High heat efficiency.
4. Finished nature of products.

By a system of fractional condensation of the mixed vapors produced by the pipe-still by which the heavy fractions are taken off at the beginning, products are formed

[1] See page 427.

[2] This process, also commonly known as the Trumble Process, has been developed by the Shell Company of California to such an extent that forty plants designed to operate under this system have been erected or are in course of erection for the Shell Company and its licensees.

[3] As far as known, this process has not been adopted in connection with any high-grade crude producing direct-steam refined stock.

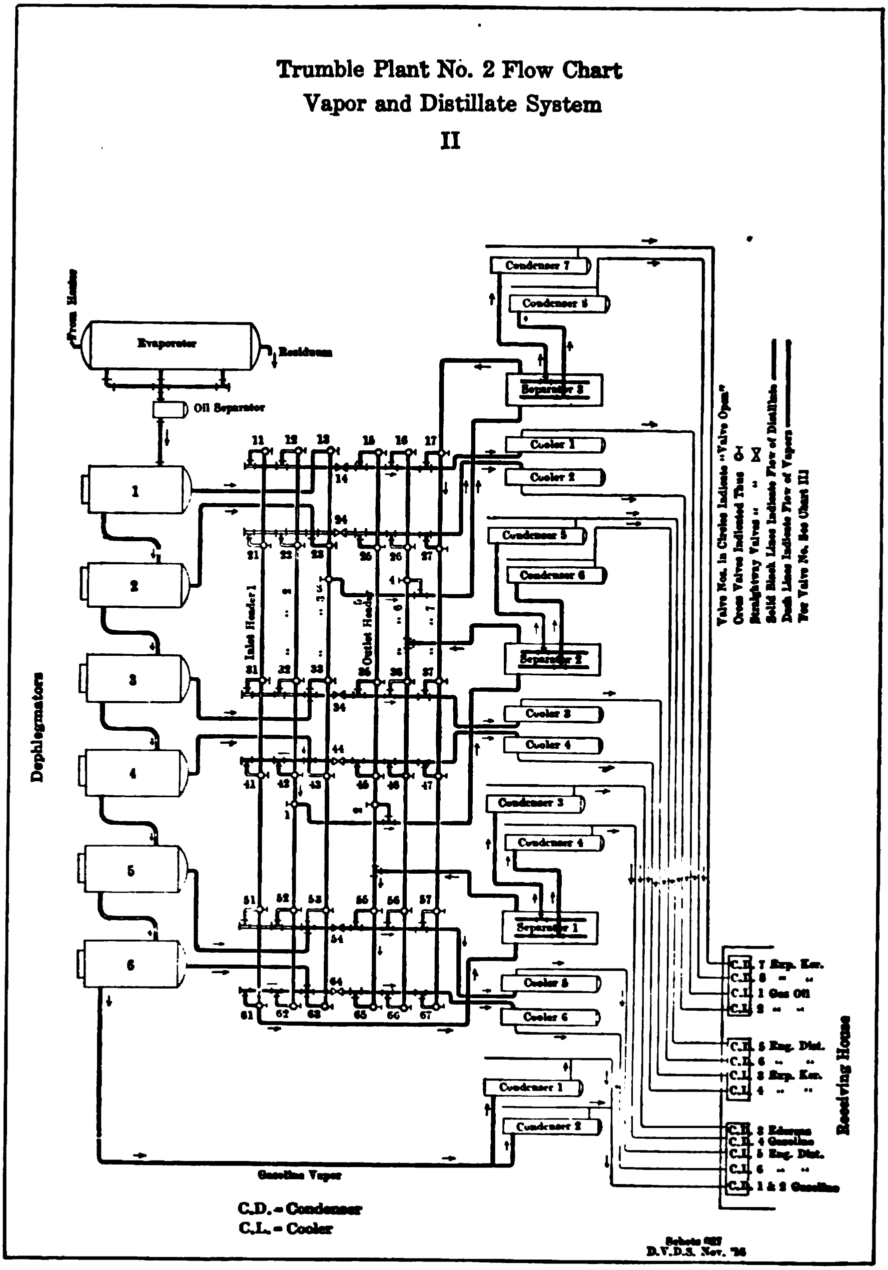

Trumble Plant No. 2 Flow Chart
Vapor and Distillate System
II
From Heater
Evaporator
Residuum
Oil Separator
Dephlegmators
1
2
3
4
5
6
Inlet Header 1
Outlet Header
Condenser 7
Condenser 8
Separator 3
Cooler 1
Cooler 2
Condenser 5
Condenser 6
Separator 2
Cooler 3
Cooler 4
Condenser 3
Condenser 4
Separator 1
Cooler 5
Cooler 6
Condenser 1
Condenser 2
Gasoline Vapor
Valve Nos. in Circles Indicate "Valve Open"
Cross Valves Indicated Thus
Straightway Valves " "
Solid Black Lines Indicate Flow of Distillate
Dash Lines Indicate Flow of Vapors
For Valve No. See Chart III
C.D. 7 Exp. Ker.
C.D. 8 " "
C.L. 1 Gas Oil
C.L. 2 " "
C.D. 5 Eng. Dist.
C.D. 6 " "
C.L. 3 Exp. Ker.
C.L. 4 " "
C.D. 3 Eng. Dist.
C.L. 5 Eng. Dist.
C.L. 6 " "
C.D. 1 & 2 Gasoline
Receiving House
C.D. = Condenser
C.L. = Cooler
D.V.D.S. Nov. '26

FIG. 159.

which do not require rerunning, nor, in some instances, even ordinary agitator treatment. It is interesting in this regard to note the statement of the Shell Company that "the gasoline produced by this process is neither separately rerun nor agitated, coming off from the condensers directly as a marketable product." [1] This system has recently been applied successfully to the production of lubricants.

The operation of this process is essentially different from "straight-run" refinery practice. Crude oil is pumped through three heat exchangers [2] to two oil-fired pipe-stills [3] and heated. It is then expanded in an evaporator, where the vapors are separated from the liquid residue. The residue (fuel oil) is used as the heat medium in the distillate separators, then it preheats the incoming crude in the heat exchangers, and goes to the run-down tanks. The vapors are first freed, in an oil catcher from suspended droplets or bubbles of residuum and are then fractionally condensed in a series of eight dephlegmators. The vapor leaving the last dephlegmator is condensed in a vertical condenser and forms the bulk of the gasoline produced. The condensates from the different dephlegmators can pass either through horizontal tubular coolers direct to the receiving house, or if necessary, can be first redistilled in the distillate separators, of which there are four. A system of manifolds and valves, conveniently arranged on an operating platform, makes it possible to interconnect the dephlegmators, separators and coolers in different ways, so as to suit conditions and obtain the best possible fractionation of the products. The vapors, or tops, from the separators are condensed in vertical condensers. The final distillates, or "cuts," pass to the receiving house through water traps to the look-box, where they are combined so as to form the required products and pass to the run-down tanks. The number of "cuts" obtainable at a plant equipped as described is seventeen. Fig. 159 illustrates the "cuts" in graphic form.

Some idea of the efficiency of the process may be had from the following operating tables:

Average Quantity of Crude Run per Unit			Per cent topped	Per cent residue	Fuel Oil Used	
Kind	Bé.	Barrels per day			Gallons per barrel	Per cent by volume
Healdton.....	31.0	7000	28	72	0.57	1.36
Healdton.....	31.0	6000	35	65	0.70	1.67
Healdton.....	31.0	4200	48	52	0.85	2.03
Yale.........	36.0	4000	53	47	0.93	2.22
Cushing......	39.0	3300	63	37	1.00	2.36

These figures include only fuel used for heaters and for superheating the steam used for the distillation.

The fractionation obtained at that plant, running on pure Cushing crude, taking off 57 per cent of total distillates from 4000 barrels of crude per day, is shown in the following table:

[1] The author substantiates this assertion where the process is used with high sulphur-bearing Mexican crudes, but is inclined to believe Lima crude would produce a gasoline requiring additional refining.

[2] For a description of the apparatus used in the Simplex Refining Process, together with various illustrations, see Figs. 17, 51, 53, 54 and 109.

[3] Ibid.

Product	Specific gravity	Initial boiling point	100° per cent	125° per cent	150° per cent	175° per cent
Gasoline	0.7416	67° C.	18.1	56.5	80.1	
Special distillate	0.7857	138°	......	......	16.5	65.3
Domestic kerosene	0.8416	180°				
Export kerosene	0.8378	214°				
Gas-oil	0.8453	220°				

Product	200° per cent	225° per cent	250° per cent	275° per cent	300° per cent	Final boiling-point	Flash
Gasoline	......	......	......	......	......	211° C.	
Special distillate	89.3	......	......	......	......	239°	84° F.
Domestic kerosene	24.5	55.4	87.4	......	......	305°	144° F.
Export keorsene	......	......	23.5	52.3	79.9	368°	80° C.
Gas-oil	......	......	13.7	30.6	71.1	368°	86° C.

The main products are gasoline, domestic kerosenes, and gas-oil, while the special distillate and the export kerosene are to be considered as by-products.

The percentage of each of these products during the same month (from Cushing and Healdton crude) were:

	Per cent
Gasoline	16.82
Special distillate	1.09
Domestic kerosene	11.47
Export kerosene	0.32
Gas-oil	5.85

The percentages, combined with the distillate tests of the products, show that a very satisfactory fractionation is obtained at the Trumble plants.

The various apparatus, by means of which this direct fractionation of the vapors from the Trumble plant is obtained, are patented (or patents covering them have been applied for) in the United States and abroad.

Heat Exchanger Data

Healdton crude, 6200 to 6500 barrels per day, 31.1° Bé.
Residue, 63 to 67 per cent, 24.0 to 24.4 Bé.
Fuel used in heaters, .63 to .69 gallon per barrel crude.
Temperature averages of 32 readings each:

	Degrees F.
Crude into heat exchangers, No. 3	45.1
Crude into heat exchangers, No. 2	86.5
Crude into heat exchangers, No. 1	157.0
Crude into retorts	246.7
Crude into evaporator	516.2

	Degrees F.
Residue out of evaporator	508.3
Residue into heat exchanger, No. 1	153.2
Residue into heat exchanger, No. 2	345.7
Residue into heat exchanger, No. 3	253.2
Residue into cooler	190.4
Residue out of cooler	179.8

Crude temperature rises	No. 3, 25.8	No. 2, 36.4	No. 1, 49.8	All, 112.0
Residue temperature drops	No. 3, 34.9	No. 2, 51.4	No. 1, 59.7	All, 146.0
Crude average per hour				36,700 Kg.
Residue average per hour				24,600 Kg.

Assume specific heat of crude at 0.45; then the amount of heat in 1000 cal. per hour absorbed by the crude is:

No. 3, 426 No. 2, 602 No. 1, 824 All, 1852

For the three heat exchangers together, the mean temperature difference is 97° C., the mean tube surface 441 square meters, the heat transfer coefficient is about:

$1,852,000 \div (441 \times 97) = 43.4$ Calories per square M. per degree C. per hour.

or 8.9 B.t.u. per square foot per degree F. per hour.

Linear velocity of crude about, .233 M. per second.

Linear velocity of residue about, .019 M. per second.

A process which has attracted considerable attention in the last year exemplifies the possibilities of mechanical development in the refining industry. This is the Sharples Process [1] for the production of bright stock from cylinder stock, and is described as follows:

The Sharples Process

This process was made possible by two mechanical developments:

1. The perfection of the Sharples Super-centrifuge, a machine which operates at a speed of 16,900 R.P.M. and develops a centrifugal or separating force 16,000 times the force of gravity.

2. The development of a rotor for the super-centrifuge, by means of which suspended solid matter, upon being separated from a liquid, can be continuously discharged from the rotor.

The advantages of the process over the older cold-settling method for manufacturing bright stock are claimed to be as follows:

1. The process is continuous.

2. The pour test of the finished product will be from 15° to 20° lower than that obtained by cold-settling.

3. The yield in bright stock will be greater, on oils of similar origin, than that produced by cold-settling, a normal 70 per cent to 75 per cent yield being increased to 88 per cent to 93 per cent.

4. The wax discharged is free from oil and has a higher melting point.

This process is for the treatment of steam-refined cylinder stock, which must be previously freed from asphalt by acid treatment or filtration; it is unsuited for the separation of crystalline wax from distillates. In the actual operation of the process the

[1] This process, developed by the Sharples Specialty Company of New York, N. Y., operates under several patents, with others pending, and has been installed in several refineries. The appearance of a battery of Sharples machines may be gathered from Fig. 160, p. 390.

FIG. 160.—A battery of Sharples wax-separating centrifuges.

asphalt-free cylinder stock, filtered to color, is diluted with naphtha; a mixture of 60 per cent naphtha and 40 per cent cylinder stock is usually satisfactory, but the mixture should have a gravity of approximately 42° Bé. at 60° F. The gravity of the naphtha should be approximately 57° Bé.[1] at 60° F. or lighter, and it should be a straight cut with a dry point not higher than 430° F.

The diluted material is next heated to a temperature of 100° F., and agitated to insure a complete solution. The solution is then chilled gradually through a period of forty-eight hours to a temperature of minus 10° F., and is then passed with the carrier liquid, which is a calcium chloride brine, continuously through a battery of Sharples Super-centrifuges of the solid-discharge type. The centrifuges separate the wax from the oil, the wax-free oil being discharged from one point and the carrier liquid, together with the wax, from another. The wax-free oil leaves the centrifuges at approximately minus 5° F., and may then be passed through an exchanger to recover its refrigeration. It is then reduced in the usual manner in standard stills, the naphtha being recovered and used again in the process. The wax is heated, centrifugally dehydrated, reduced and freed from naphtha, finding a ready market as a petrolatum base. The essential feature of the centrifugal separation of wax from cylinder stock is the continuous discharge of the wax from the machines. For this purpose a special rotor has been constructed. Chilled brine, termed the carrier liquid, is passed through the centrifuges with the oil. As the carrier liquid is heavier than either the oil or the wax, it forms a cylindrical layer outside of the wax, next to the shell of the rotor, and acts as a carrier for the wax. The wax-free oil is thus discharged from one outlet of the centrifuges and a mixture of the carrier liquid and wax is discharged from the other.

The daily cost of operation of a plant capable of producing 200 barrels of bright stock per day, on the basis of early 1921 costs, is given by the Sharples Company as follows:

Operating Costs

40 tons refrigeration at $1.00, day charge	$40.00
Power for centrifuges, 1½ K. W., per centrifuge, 11 centrifuges, 24 hour operations at 4 cents per K. W., hour, day charge	15.84
Power for pumps, average 2 K. W. 9 pumps, 24 hours, day charge	17.28
Upkeep, repairs and loss of solvent, etc., estimated day charge	80.00
Labor, three men, three shifts, at $5.00 per man, day charge	45.00
Interest on investment, 6 per cent per annum, day charge	27.75
Cost of steam for reducing cylinder stock, 1 cent per gallon finished stock, 42 gallons to barrel, 200 barrels per day, day charge	84.00
Total cost of converting 222 barrels, amber filtered cylinder stock into 200 barrels bright stock and 22 barrels of wax	$309.87
Cost per gallon bright stock	$ 0.037

Edeleanu Process

The possibilities of the separation of petroleum products by selective solvent action are brought out in the Edeleanu[2] process, which is particularly applicable to the treatment of aromatic burning-oil distillates, and is described as follows:

[1] Naphtha of a somewhat lower gravity, if otherwise of proper end-point, is permissible with western stocks, since these, being of low gravity themselves, do not destroy the 42° Bé. gravity of the mix, specified as most desirable for efficient wax precipitation.

[2] This process, the discovery of Dr. L. Edeleanu, the eminent Rumanian chemist, is covered by U. S. Patent No. 911,553, Feb. 2, 1909; British Patent No. 11,140, May 22, 1908; and by German Patent No. 216,459, May 23, 1908, of the Disconto-Gesellschaft. It is successfully operated on a large scale at Ploesti, Rumania; other large plants designed to employ it have been installed or are in process of construction in Galicia, Rumania, Borneo, India, etc.

From the very inception of the petroleum industry, sulphuric acid has been employed in the treatment of burning-oil distillates, for the purpose of removing resinous matter and certain hydrocarbons, such as olefines, which exert a prejudicial influence on burning quality. These constituents are separated out in the form of residual sludge, their further recovery being of doubtful commercial value. For removing constituents of a more pronounced smoke-producing character, i.e., aromatic hydrocarbons, considerable quantities of sulphuric acid, sometimes in the state of "fuming acid," [1] are required, the amount depending upon the proportion of these hydrocarbons present in the distillate. This often renders the operation decidedly costly. The application of large quantities of sulphuric acid, especially in the fuming or anhydride state, has an additional drawback. It not only attacks the aromatic and unsaturated hydrocarbons, but also destroys a certain quantity of the saturated constituents. The process thus has the disadvantage of still further reducing the proportion of useful hydrocarbons finally obtained.

In order to avoid the bad features of the treatment hitherto employed, it is necessary to substitute for the purely chemical treatment, a physical method of extraction. The constituents of the petroleum must be treated with a solvent which dissolves the hydrocarbons of the unsaturated aromatic group but leaves the saturated hydrocarbons undissolved. In this way the two classes of hydrocarbons can be separated from one another and each can be employed in a suitable way.

The most important problem in this connection was that of discovering an appropriate solvent; finally, liquefied sulphur dioxide [2] was found to be the best material. This substance readily dissolves the unsaturated hydrocarbons, as well as certain aromatics which are responsible for the unsatisfactory burning quality and odor characteristic of certain burning-oils, while it leaves undissolved a non-smoke-producing kerosene. Frasch [3] attempted to achieve the same object by the application of alcohol, but liquefied sulphur dioxide is said to possess certain advantages over the former solvent. The chief superiority of liquefied sulphur dioxide apart from cheapness, consists, according to Edeleanu, in the fact that it can be readily recovered from the solution, so that in practice the solvent can be used again and again in a cycle of operations, without any appreciable loss.

The Edeleanu process makes use of the peculiar solvent property of liquid sulphur dioxide. If the distillate is agitated with this chemical at a low temperature the aromatic compounds are dissolved, but the paraffins and naphthalenes are unaffected. Moreover, owing to the difference in the specific gravities, two distinct layers are formed, so that it is quite easy to separate them from one another.

The process itself is comparatively simple. A certain quantity of the sulphur dioxide is added to the petroleum distillate and is dissolved. The addition is continued after the distillate is saturated; each portion of sulphur dioxide added after the saturation

[1] For a description of the method of applying fuming sulphuric acid and sulphuric anhydride to California distillates, see p. 370.

[2] Edeleanu, Bull. Am. Inst. Min. Eng., 1914, No. 93, 809. This contribution, delivered at the Pittsburgh meeting, October, 1914, is freely quoted in the preceding and succeeding descriptions of the Edeleanu process.

[3] Frasch, U. S. Patent No. 951,272, March 8, 1910, describes the treatment of Beaumont or similar distillates, of at least a portion of the smoky burning-oil fractions, with a solvent, such as ethyl or methyl alcohol, which has a different effect on the smoke-producing and non-smoke-producing components of the fraction. Separation of a kerosene burning without smoke is thus effected, the solvent being recovered and used repeatedly. This process, after experimentation on a large scale at the Bayonne Refinery of the Standard Oil Company, was abandoned on account of difficulty in recovering the solvent. For purposes of comparison, see German Patent No. 202,776, issued to Hermann Guttmann, May 18, 1907; and Maset, Met. grasses, 2, 1534.

point is reached dissolves the aromatic constituents and separates out with them as a distinct layer. Thus, as the treatment is continued, the distillates become poorer and

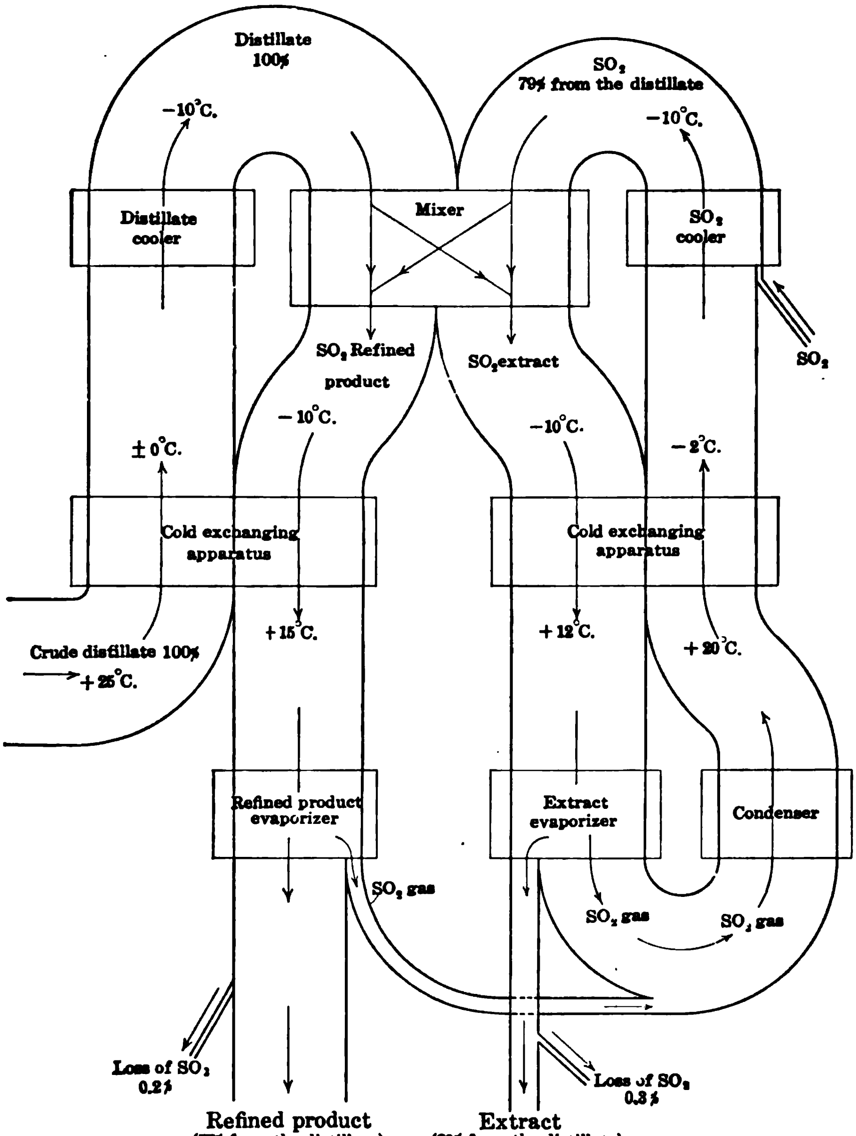


FIG. 161.—Plan of the Edeleanu process.

poorer in aromatic hydrocarbons until ultimately a refined distillate is obtained, which contains only a small amount of sulphur dioxide, and is practically free from the objectionable aromatic constituents. The solubility of the latter, however, is some-

what dependent on the temperature employed.[1] As the temperature rises the solubility of the paraffin hydrocarbons and the naphthalenes—which at low temperatures are practically insoluble—increases rapidly; whereas the aromatic hydrocarbons are soluble in sulphur dioxide at all temperatures. It is therefore important, as noted by Edeleanu, that the temperatures should be maintained at a suitably low level, particularly in the case of a distillate rich in aromatics.

The removal of the aromatic hydrocarbons from an illuminating oil distillate causes not only a lowering of the specific gravity, but also an increase in burning capacity and illuminating power. The richer a distillate is in aromatic and heavy hydrocarbons, the more marked is the improvement brought about by treatment with sulphurous acid. The effect of the Edeleanu process is clearly discerned when a Bustenari distillate is treated. While the chemical process hitherto employed produces a very inferior illuminating oil which smokes badly and develops only 7 candle-power when burned in a 14-unit Cosmos burner, the treatment with liquid sulphur dioxide produces an oil equal to the best American and Russian oils.

Utilization of by-products.—The extract obtained in addition to illuminating oil contains, as mentioned, aromatic hydrocarbons and hydrocarbons rich in carbon. On account of their inferior burning quality, they cannot be included in the kerosene fractions; nevertheless, it is claimed that they can be made marketable by dividing the extract into two grades by redistillation, the lighter fraction as a turpentine substitute, or, mixed with light gasoline or benzol, as a motor spirit of high efficiency, and the heavier as motor oil for Diesel motors. The extract is, therefore, as regards the possibility of turning it to account, at least equally as valuable as the distillate.[2] Edeleanu also states that additional experiments have shown that the extract can be resolved by special means into the lower homologues of the aromatic hydrocarbons. By pyrogenic distillation the hydrocarbons contained in the extract are split up, and, besides a gaseous part, a large percentage of tar is produced. The latter is distinguished from tar derived from coal, by its higher content of the lower members of the aromatic series of hydrocarbons.

Effect of the Edeleanu process on sulphur-bearing distillates.—The author further notes that the liquid sulphur dioxide also possesses the property of dissolving out from crude distillates, certain sulphur-containing constituents. For instance, when a Mexican distillate of 0.803 specific gravity, with a sulphur content of 0.6 per cent, is treated, the oil obtained shows only 0.08 per cent of sulphur; another oil of 0.79 specific gravity, with a sulphur content of 0.46, could be reduced to a percentage of sulphur of 0.04.

Edeleanu [3] gives the following description of the process as applied to the Rumanian distillate from Bustenari:

The dried distillate to be treated passes through filters charged with salt, is collected in a receiver, and finally reaches the distillation cooler after going through a cold-exchanging apparatus. The temperature of the distillate is first lowered in the cold-exchanging apparatus, and it is then further cooled in the distillation cooler itself until

[1] The degree to which the process is affected by the temperature naturally depends on the nature of the material treated. For instance, in the case of a distillate from Borneo, which contained as much as 40 per cent of aromatic hydrocarbons, treatment with 66 per cent liquid sulphur dioxide at $-7°$ C. produced no separation; but a considerable proportion of the aromatic constituents could be separated at $-10°$. On the other hand, in the case of a Mexican distillate, which contained only about 17 per cent of aromatic hydrocarbons, treatment with an equal amount of liquid sulphur dioxide produced separation even at a temperature higher than 10° C. In practice, it is found that each distillate requires special treatment, according to its composition, in order to obtain the best results.

[2] In this country, under present (July, 1921) market conditions, the lighter fraction would be decidedly more valuable than the kerosene distillate portion.

[3] Loc. cit.

it reaches the desired low temperature. Similarly, the liquid sulphur dioxide coming from the vessel passes through a second cold-exchanging apparatus, where its temperature is reduced somewhat, and thence to the sulphur dioxide cooler itself, where it receives the necessary final cooling.

The distillate at about $-10°$ C. is now let into the lower mixer, a cylindrical vessel which is provided with level gages, and in its lower part with gage glasses, so that the reaction in the liquid may be accurately observed.

The introduction of the liquid sulphur dioxide into the mixer begins immediately. The sulphur dioxide is at first entirely absorbed by the distillate, without any appreciable change in the liquid. As soon as the distillate is saturated with the liquid sulphur dioxide, dark cloud masses begin to rise, and the color changes suddenly to a deep brown. This change of color is brought about by the action of the liquid sulphur dioxide which has become loaded with the aromatic hydrocarbons and which separates out and deposits at the bottom of the mixer. There are now two sharply divided layers which can be distinctly observed through the level gages. As soon as a certain quantity of extract is formed, the drawing-off commences; at the same time additional quantities of liquid sulphur dioxide are supplied to the mixer.

The extract is drawn by the extract pump through the cold-exchanging apparatus into the extract evaporator. In the cold-exchanging apparatus it meets the comparatively warm distillate flowing to the distillation cooler (as described above), by which its temperature is considerably raised. In this way the distillate receives a preliminary cooling and the extract a preliminary warming. The latter is then further warmed in the extract evaporator, which is provided with heating coils. This causes the rapid evaporation of the dissolved sulphur dioxide which flows directly into a condenser, where it accumulates in the form of a liquid; it is then stored in the reservoir, whence it commences its cycle afresh.

As soon as the greater part of the sulphur dioxide contained in the extract has been driven off, the evaporation is gradually brought to a stop. The final remaining portion of the sulphur dioxide is held very tenaciously by the extract, and cannot be driven off merely by the application of heat. In order to prepare the extract evaporator for a fresh charge, the extract with the small amount of sulphur dioxide which it still contains, is run into an auxiliary evaporator. Here the remainder of the sulphur dioxide is drawn off by a sulphur dioxide gas pump under the continuous application of heat, and is sent to the condenser. This is continued until about 0.3 per cent still remains in the extract, when the latter is removed from the auxiliary evaporator.

The refined product is pumped through the second cold-exchanging apparatus into the second evaporator. In the cold-exchanging apparatus it meets the liquid sulphur dioxide flowing from the tank to the cooler, and is warmed until the temperature of the two liquids is practically the same. In this way the liquid sulphur dioxide receives a preliminary cooling (just as in the case of the distillate). The refined product is then collected in the evaporator and undergoes a process of evaporation similar to that undergone by the extract. By means of heat and continued suction the sulphur dioxide is almost completely removed, only about 0.1 or 0.2 per cent remaining; at this stage the refined-product evaporator is emptied.

The treated distillate, after being washed and neutralized with an alkaline solution, may be used as finished illuminating oil. In some cases subsequent treatment with very small quantities of sulphur dioxide helps to produce a " water-white " color.

The exhaust steam from the steam engine which drives the plant is utilized for the heating of evaporators.

While the evaporating process is still going on in the extract evaporator a new operation takes place, a freshly cooled distillate being admitted to the mixer and saturated with liquid sulphur dioxide, until fresh quantities of extract settle out. By this time

the evaporation in the extract evaporator is also finished and the apparatus emptied, so that the new operation is able to proceed without interruption.

The cooling of the distillate and sulphur dioxide collected in the two cooling vessels is effected in the usual manner with the help of cooling coils, which form a part of a separately working cooling machine. The cold-producing medium enters the cooling tubes as a liquid, evaporates on account of the continuous low pressure produced by the suction of the compressor of the cooling machine, and abstracts from its surroundings, i.e., from the distillate and liquid sulphur dioxide, the heat required for its evaporation. The vapor of this cooling medium is afterward sucked up by the compressor and led to the condenser of the cooling machine, where it is again collected in liquid form.

The method of working is shown graphically in Fig. 161, page 393. This diagram shows how fresh distillate is continuously entering the system, how it finally leaves the system split up into refined product and extract, and how the sulphur dioxide, which effects the splitting up, is recovered with the exception of a very small quantity, and is then used again for the process, making a complete cycle.

Edeleanu further states:

"It may also be seen that of the distillate put into the system nothing is lost; the products of the treatment, viz., the refined product and the extract, are equal in volume to the original distillates.

"As the sulphur dioxide performs a complete cycle, it cannot, after once entering the system in a pure anhydrous condition, give rise to any undesirable complications. It is well known that liquid sulphur dioxide is quite inactive toward metals, so that there is no fear of the apparatus becoming injured or destroyed in the course of time.

"However, great care must be taken that no moisture is introduced into the system with the distillate. The latter should, therefore, as mentioned above, pass through several drying filters before it enters the apparatus, so that all the moisture may be removed. Inasmuch as the system is perfectly air-tight throughout, there is, of course, no possibility of moisture from the atmosphere penetrating into it.

"The fact that the whole of the apparatus, pipes, valves, etc., is completely air-tight explains the fact that scarcely any smell of sulphur dioxide is perceived in the plant. This is of the greatest importance for the welfare of the workmen who are in attendance at the plant."

All the important pipes with their control valves are placed on a regulating table, so that the operator in charge of the refining process can take care of all the necessary regulating and connecting manipulations without leaving his place of observation.

Working results.—The following table, taken from Edeleanu's contribution,[1] gives the working results of the plant at Ploesti which is capable of treating, on an average, about 65 tons of distillate per twenty-four hours.

Specific gravity of the crude distilled to be treated	0.820
Average time of operation, minutes	68
Quantity of distillate treated at each operation, kilograms	3115
Temperature in the mixer, degrees centigrade	−10°
Specific gravity of treated product	0.8028
Specific gravity of extract	0.8691
Sulphurous acid left in the treated product, per cent	0.16
Sulphurous acid left in the extract, per cent	0.36
Consumption of fresh steam per operation, kilograms	1200
Consumption of fresh steam per 1000 kg. distillate, kilograms	385
Consumption of exhaust steam per operation, kilograms	648

[1] Loc. cit.

Consumption of exhaust steam per 1000 kg. distillate, cubic meters	208
Cooling water used per operation, cubic meters	17.1
Cooling water used per 1000 kg. distillate, cubic meters	5.5
Loss of sulphurous acid per operation, kilograms	17.5
Loss of sulphurous acid per 1000 kg. (distillate), kilograms	5.6

From the above figures, the cost of treating a Rumanian Bustenari distillate can be calculated as follows:

Cost of Treatment in a Plant of 65 Tons Daily Capacity

Cost of Plant:	Francs	
Machines and apparatus	130,000	
Buildings, construction, freight, duty and other expenses	100,000	
Total	230,000	
Amortization and Interest	Francs	
Amortization = 10 per cent of 130,000 francs	13,000	
Amortization = 5 per cent of 100,000 francs	5,000	
Interest on invested capital = 5 per cent of 230,000 francs	11,500	
Total	29,500	
In 325 working days, at 65 tons per day, there will be 21,125 tons treated, so that the amortization and interest amount to 1396 francs per ton, or per 100 kg.		0.140 franc
Maintenance, Labor, etc.:	Francs	
Repairs, working materials	6,000	
Wages and salaries	8,000	
Insurance, 1½ per cent	3,450	
Lighting and heating	2,400	
Drying salt, unforeseen expenses	3,000	
Total	22,850	
The cost of maintenance and labor, therefore, amounts to 1.082 francs per ton, or per 100 kg.		0.108 franc
Cost of Materials:		
There are required for each 1000 kg. of distillate:	Francs	
385 kg. fresh steam at 3.50 francs per ton	1.35	
208 kg. exhaust steam at 1.50 francs per ton	0.31	
5.5 cu. m. cooling water at 0.04 francs per cubic meter	0.22	
5.6 kg. sulphurous acid at 18.00 francs per 100 kg.	1.01	
Cost of materials per 1,000 kg.	2.89	
Cost of materials per 100 kg.		0.289 franc
The total costs of treatment per 100 kg., therefore, amount to		0.537 franc

or practically 0.54 franc per 100 kg. of distillate or 3.9 shillings per ton. It must also be taken into account that 18 francs per 100 kg. of sulphurous acid is a very high figure and refers to imported sulphurous acid. The cost of this material is very much lower when the sulphurous acid used is produced in the country itself, or actually in the refinery.

Cost of Treatment in a Plant of 500 Tons Daily Capacity

Cost of Plant:	Francs	
Machines and apparatus	1,100,000	
Buildings, construction, etc.	500,000	
Total	1,600,000	
Amortization and Interest:	Francs	
Amortization = 10 per cent of 1,100,000 francs,	110,000	
Amortization = 5 per cent of 500,000 francs,	25,000	
Interest on invested capital = 5 per cent of 1,600,000 francs,	80,000	
Total	215,000	
In 325 working days, at 500 tons per day, there will be produced 162,500 tons, so that the amortization and interest amount to 1.323 francs per ton, or per 100 kg.		0.132 franc
Maintenance, Labor, etc.:	Francs	
Repairs, working materials	40,000	
Wages and salaries	30,000	
Insurance, 1½ per cent	24,000	
Lighting and heating	10,000	
Drying salt, unforeseen expenses	20,000	
Total	124,000	
Brought forward		0.132 franc
The cost of maintenance and labor, therefore, amount to 0.763 franc per ton, or per 100 kg.		0.076 franc
Cost of Materials:	Francs	
There are required for each 1,000 kg. of distillate:		
385 kg. fresh steam at 3.50 francs per ton	1.35	
208 kg. exhaust steam at 1.50 francs per ton	0.31	
5.5 cu. m. cooling water at 0.04 francs per cubic meter.	0.22	
5.6 kg. sulphurous acid at 10.00 francs per 100 kg	0.56	
Cost of materials per 1,000 kg.	2.44	
Cost of materials per 100 kg.		0.244 franc.
Total cost of treatment		0.452 franc

or roughly, 0.45 franc per 100 kg. of distillate or 3.26 shillings per ton. In this case the cost of sulphurous acid is taken as 10 francs per 100 kg., sulphurous acid produced on the spot being considered. The production is liberally estimated throughout.

The above tables are based on figures actually obtained from the existing plants. It is, however, to be anticipated that with further perfection of the process the costs will be reduced even more.

The chief advantages are summarized by Edeleanu as follows:

1. The process makes it possible to obtain illuminating oil of good quality from the greatest variety of low-grade oils.

2. The sulphur dioxide employed is cheap, and practically all of it is recovered.

3. Sulphur dioxide required for the process can even be obtained from the acid sludge available in the refinery in the manufacture of lubricating oils.

Petrol-Alcohol (Petrohol) Process

A purely chemical process of very recent development, i.e., that of Carleton Ellis for the production of Petrol-Alcohol [1] (isopropyl alcohol) is next discussed as showing the great field for applied chemical research in refinery by-products, hitherto considered as unavoidable wastes.

The production of petrol-alcohol, or petrohol,[2] as the new solvent has been termed, from waste still gas, is based on the reactivity of the olefine content of the latter with sulphuric acid. While ethylene, propylene, butylene, amylene and the like are all present, in quantities varying from a trace to appreciable percentages, in practically all waste still gases, the gas produced from cracking or high-pressure distillation contains a particularly large percentage of propylene, and when acted upon by sulphuric acid of proper strength [3] unites to form propyl sulphuric acid in accordance with the reaction:

$$\begin{array}{lcl} CH_3 & & CH_3 \\ | & & | \\ CH & + H_2SO_4 = & CH(HSO_4) \\ | & & | \\ CH_2 & & CH_3 \end{array}$$

When this compound is treated with water, propyl alcohol is formed, and may be separated by distillation, from the acid and polymers present, the following reaction indicating the hydrolysis:

$$\begin{array}{lcl} CH_3 & & CH_3 \\ | & & | \\ CH(HSO_4) & + H^2O = & CHOH + H_2SO_4 \\ | & & | \\ CH_3 & & CH_3 \end{array}$$

[1] This process, secured by U. S. Patent, is now owned by the Standard Oil Company of New Jersey and is in actual operation at its Bay Way plant, where several hundred gallons a day of the new product are being manufactured. The discoverer, Ellis, is the inventor of certain hydrogenation processes, which are also of great importance to the petroleum industry.

[2] Ellis, Petroleum, 1 (1921), 40. This contribution has been freely used in the preparation of the above account.

[3] A study of the effect of dilution of the acid and control of temperature resulted in ascertaining that by the use of sulphuric acid of 80 to 85 per cent strength and temperatures of between 10° and 20° Centigrade, a substantial conversion of the olefines to alcohols resulted. It was found that the alkyl sulphuric acid obtained was unstable and had to be hydrolysed promptly to avoid excessive polymerisation, and formation of high-boiling point olefines

These reactions constitute the essential steps in the process, which, as applied to the production of propyl and other alcohols from the refinery gases in commercial quantities involves certain additional precautions, the final procedure being as follows:

1. Removal of H_2S (hydrogen sulphide) and moisture.
2. Making of acid extract.
3. Settling to remove oils.
4. Hydrolysis of acid extract.
5. Distillation.
6. Rectification.
7. Reconcentration of H_2SO_4 (sulphuric acid).

The removal of hydrogen sulphide which is often present to the extent of 1 per cent or more, is of importance, as this constituent not only reacts with sulphuric acid and causes dilution of the latter, but apparently also combines in some manner with the alkyl sulphuric acid, forming compounds which on subsequent distillation yield bodies possessing a very bad odor and making the alcohol correspondingly hard to refine.

The hydrogen sulphide is therefore removed in a suitable absorbing tower. Moisture, if present, may be reduced to a sufficient extent by passage through sulphuric acid of 1.6 specific gravity. The purified gas is then passed into sulphuric acid of 1.8 specific gravity [1] to form the alkyl sulphuric acid. This absorption may be carried out in towers in a continuous manner or by the batch method, that is, charging a quantity of sulphuric acid by passing the gas through it.

If the second method is followed, the gas is blown through the acid, or through a mixture of acid and oil. After several hours of such treatment the acid becomes converted, as far as this is possible, to alkyl sulphuric acid. When gas analysis shows that the absorption of olefines has practically ceased, the acid is permitted to settle and separate from any oil present. The acid material thus obtained is a brown syrup of less specific gravity than the original acid. This extract is then submitted to hydrolysis by mixing with several volumes of water, separating any oils and water-insoluble alcohols and distilling the aqueous extract in a lead-lined still to get an alcoholic solution containing about 20 per cent of propyl alcohol. This solution is rectified until concentrated to the requisite degree. The sulphuric acid remaining in the still is concentrated by the distillation to about 35 per cent, and may be taken to ordinary acid concentrators which restore its strength to a specific gravity of 1.8. It is then ready to repeat the cycle of operations.

Ordinarily, when the operation is begun with sulphuric acid of 1.8 specific gravity, containing about 87 per cent of sulphuric acid, the specific gravity at the finish will be 1.4, and the expansion due to olefines and formation of polymers will amount to about 80 per cent.

While ethylene is present to the extent of several per cent [2] in refinery gases, its absorption requires highly concentrated sulphuric acid and high temperatures, involving

[1] The acid increases in temperature during the absorption. If the temperature rises much above 20° C., polymerization occurs, with material reduction in yields. Provision must therefore be made for cooling the absorbent acid.

[2] The production of olefine-containing gas is enormous, particularly in plants where cracking processes are installed. One plant produces 10,000,000 to 12,000,000 cubic feet daily, varying in olefine content up to 10 or 12 per cent. The gases from the Burton pressure stills are especially well suited for the production of alcohols, being available at 90 pounds pressure, and containing among other constituents:

	Per cent
Available alcohol-producing olefines	5
Ethylene	2–3
Hydrogen sulphide	1

a number of additional difficulties. The absorption of propylene by sulphuric acid takes place readily in the cold, in simple absorption towers. In distilling the dilute propyl alcohol to make the concentrated product, it has been found that when propyl alcohol and ethyl alcohol are distilled from solutions of the same strength the propyl alcohol affords a higher concentration in the vapor mixture than the ethyl alcohol. Propyl alcohol in some respects is easier to manufacture than ethyl alcohol and Ellis claims that it will do the same work for most technical purposes.

Except for the fact that it is insoluble in a saturated, cold calcium chloride solution, propyl alcohol responds to practically all of the solubility tests of ethyl or grain alcohol, and closely resembles the latter in boiling point, as the following comparison will show:

	Normal propyl alcohol	Isopropyl alcohol	Ethyl alcohol
	Constant boiling mixture		
Boiling point		80.37° C.	78.15° C.
Per cent alcohol by volume		90.3	97.3
Specific gravity		0.8190	0.8065
	Absolute		
Boiling point	97.4° C.	82.44° C.	78.30° C.
Per cent alcohol by volume	100	100	100
Specific gravity	0.8044	0.7855	0.7893

Propyl alcohol, i.e., isopropyl alcohol,[1] as marketed by the Standard Oil Company under the name of Petrohol, is of the following composition:

Isopropyl alcohol	90.3 per cent
Water	9.7 per cent
Boiling point	80.2° C.

When it is injected intravenously its toxic effect is twice as great as that of ethyl alcohol, but it appears to be much less injurious with respect to inhalation of vapors than either methyl (wood) or ethyl (grain) alcohol, a fact which recommends it for industrial use.

[1] The name propyl alcohol (propanol), C_3H_7OH, is properly applied to normal propyl alcohol, $CH_3 \cdot CH_2 \cdot CH_2 \cdot OH$, and its isomer, secondary isopropyl alcohol, $CH_3 \cdot CH(OH) - CH_3$. Both of these alcohols occur in fusel oil, and are agreeable-smelling liquids, miscible in all proportions with water. For solvent use the difference between normal propyl and isopropyl alcohol is unimportant; hence the name propyl alcohol is sufficient to classify Petrohol for ordinary reference. Chemically, it is of interest to know that Ellis was able to produce isopropyl acetic ester by direct reaction with sodium or other acetate with the alkyl sulphuric acid, thus:

$$CH_3 \cdot CH(HSO_4) - CH_3 + CH_3 \cdot COONa = CH_3 \cdot CH(COO \cdot CH_3) - CH_3 + NaHSO_4.$$

He was also able to obtain acetone by catalytic oxidation of the isopropyl alcohol, according to the following reaction:

$$CH_3 \cdot CH(OH) \cdot CH_3 + O = CH_3 \cdot CO \cdot CH_3 + H_2O.$$

The same objective was also reached by dehydrogenation, as shown by the following equation:

$$CH_3 \cdot CH(OH) \cdot CH_3 = CH_3 \cdot CO \cdot CH_3 + H_2.$$

These reactions show the great possibilities of chemistry as applied to the by-products of the petroleum industry.

The efficient recovery of sulphuric acid from waste sludges has long been one of the problems of the refining industry,[1] the number of patents granted,[2] both in this country and abroad, testifying to its importance. Many of the early patents have expired, not a few of the principles embodied being used in common by many of the later processes. This is true especially of those relating to decomposition of sludge and separation of weak acid.[3] The chief difficulty, however, has been the successful concentration of the separated acid, the common American practice of concentrating to 60° Bé. in lead pans,[4] and finishing to 66° in cast-iron pans [5] or glass retorts [6] being highly inefficient both from an operating and a recovery standpoint. The average yield of plants following this practice rarely exceeds 80 and is usually not over 70 per cent of the theoretically recoverable 66° acid present in the separated acid.

Increased efficiency in acid-plant operation has been obtained during concentration by allowing air to bubble through acid maintained at an elevated temperature, and it is claimed that high fuel economy is secured by the use of a cascade system of semi-

[1] As early as 1864, R. G. Loftus (U. S. Patent No. 43,157, June 14) proposed to dilute the spent acid with 50 per cent of water, agitating in the meantime, then allow the contents to settle and to draw off the oily matter. The diluted acid was then concentrated by evaporation from 1.65 to 1.70 and again subjected to dilution and settling. After the clear liquid had been siphoned from the heavier impurities, the acid was again evaporated to from 1.65 to 1.70 and finally concentrated in glass, or other suitable container to 1.845 specific gravity.

[2] Other U. S. Patents are those of Penissat, No. 204,224, May 28, 1878; Bower, No. 230,171, July 20, 1880; Clark, No. 232,685, Sept. 28, 1880; Breinig, No. 306,897, Oct. 21, 1884; Grousilliers, No. 378,774, Feb. 28, 1888. Of the more modern U. S. patents, involving processes in present use, those of John L. Gray, i.e., No. 923,427, No. 923,428, and No. 923,429, issued June 1, 1909, are of decided interest covering several claims relative to the use of steam, water, and air in separation. Tienen, U. S. Patent No. 1,000,646, August 15, 1911, operates on a mixture of 52° Bé. separated acid, together with the hydrocarbons present at 105 pounds pressure, and at a temperature of 140° to 165° C. (284° to 330° F.). It is claimed that the combined liquid separates into two layers, the upper containing oil and the lower sulphuric acid. Of the various foreign patents, that of the Steaua Romana Petroleum G. m. b. H. (German Patent, No. 221,615, June 19, 1909) is of interest in that it allows separated black acid to flow continuously into pure boiling concentrated sulphuric acid in the presence of an oxidising current of air, the evolved acid vapors being subsequently condensed and reconcentrated in standard apparatus. Other foreign patents have been granted, but lack of space prevents their description. Reference is made to German Patents, No. 257,763, Oct. 2, 1910; No. 261,777, Jan. 12, 1911; and No. 212,000, Aug. 6, 1907.

[3] The basic principles of separation described in the Loftus Patent and also in that of Farrar and Gill (U. S. Patent, No. 206,309, July 23, 1878), in which the acid tar is mixed with hot water, "steeped" with heat, cooled and settled, form the foundation of all present separation processes.

[4] The lead concentrating pans, commonly employed in American practice, vary considerably in size in the different plants. Units 5 feet wide by 50 feet long by 10 inches deep, as well as a series of shorter pans of the same width, 15 to 20 feet long are not uncommon. Such pans are invariably constructed of 10-pound "chemical" lead, and are supported by perforated cast-iron plates laid over the furnace flues. Heat for concentration is supplied by combustion of the separated acid oil.

[5] Acid leaves the last compartment or pan of the series at about 61° to 62° Bé. and generally passes to cast-iron stills or pans usually about 4 feet wide by 8 feet long by 10 inches deep, provided with hoods lined with acid-resisting material. Here the 62° acid is concentrated to 66° Bé., leaving the end pan (two pans are commonly employed) at 450° F. The evolved vapors are condensed in a scrubbing tower, and the weak acid produced is returned to process. It is claimed that many special castings offered on the market are highly resistant to acid, but at the best the life of concentrating pans is an uncertain proposition, acid loss from their failure amounting to from 2 to 10 per cent in the average restoring plant.

[6] In a few refineries, acid is restored in the final stage in glass retorts or "bottles," the latter holding about 53 gallons or 755 pounds of 62° Bé. (81.30 per cent H_2SO_4), finishing as 66° acid of 93.5 per cent acidity, and usually yielding 90 per cent of the theoretically obtainable 66° acid present in the 81.3 per cent acidity charge. When bottles are properly set and intelligently handled, the loss from breakage in a "bottle" plant is small, but the operation is intermittent, and somewhat dangerous, and the fuel cost high. The latter amounts in oil to 10 to 14 per cent by weight of the concentrated acid produced.

fused silica basins;[1] but the direct process of the Chemical Construction Company,[2] eliminating all manner of pans, shows the advance in chemical engineering that has taken place in the last few years. This process is therefore selected for detailed description as typical of the changes in special refining processes for recovery of by-products.

Direct Process for Recovering Sulphuric Acid

The apparatus employed in this process is for the purpose of concentrating separated sludge acid to at least 66° Bé., and at the same time separating the sludge from the acid. This is accomplished in two stages. The first stage of concentration carries the acid from 57° to 61° Bé. At this strength and at a properly regulated temperature, the principal sludge separation takes place. The second stage of concentration carries the acid to 66° Bé.

First stage.—The weak separated sludge acid, resulting from the dilution and separation of the original product,[3] is elevated to a distributing tank located on the top of the preheating tower. Connected with this preheating tower is a flue constructed so as to accommodate a bath of acid. Entering this flue are numerous acid-proof pipes that extend several inches below the surface of the acid.

Hot air is furnished through a main header and is distributed through branch headers to the acid-proof iron pipes. The air has a temperature of 1100° to 1200° F. and is maintained at a pressure only sufficient to allow it to ooze through the acid at a pressure of about 20 inches of water. The air enters this acid, bubbles through it and drives off the water, leaving the stronger acid together with the sludge, both of which are drained off continuously.

In the preheating tower this sludge acid is preheated by the exit gases and as much of the heat as possible is thus utilized. The gases leave this tower at a low temperature. In some cases a scrubbing tower is erected for the purpose of removing any organic compound. This is unnecessary in many cases, the necessity for it depending somewhat on local conditions and the nature of the sludge.

The partly concentrated acid, together with some sludge, is gradually drawn off, through an outlet, into coolers. From the coolers it enters large tanks provided for intermediate storage, in which the principal separation of the sludge from the acid takes place. The sludge is raked off into refuse carts or troughs as needed. At this stage some of the hydrocarbons are driven off, but it is claimed that no sulphuric acid at all is lost. Ample tank room should be provided as each day's run should be allowed to stand a day or two in order to accomplish complete separation.

At the foot of the preheating tower a flue, as above mentioned, is provided with clean-out openings, in order to clean out any sludge that settles and does not come out with the acid. A steam or air jet is provided at the exit flue in order to create

[1] The Thermal Syndicate Company, operating with vitreosil basins in cascade, claims to recover 95 per cent of the 93 per cent acid present in the 60° acid, with a fuel consumption of about 14 per cent by weight, based on the quantity of strong acid produced, and on a coal running about 13,000 B.t.u. per pound (9.2 per cent if acid oil is used as fuel).

[2] This company operates under U. S. Patents No. 1,195,075, No. 1,264,509, and No. 1,264,182. It has large plants in operation at Buffalo, N. Y., and at Bayonne, N. J., with a third plant under construction at Providence, R. I. It is claimed that the Bayonne plant operates at 90 to 95 per cent efficiency, using only 40 to 50 gallons of fuel oil per ton of finished acid.

[3] The original separation of sludge acid is commonly carried out in lead-lined vats or "cookers," in which the acid is mixed with the requisite amount of water to produce an aqueous extract of 29° to 30° Bé., of 35 per cent acidity. At this strength the greater part of the tar and oil floats to the top, leaving a clear acid, containing about 1.5 per cent of tar and oil to be drawn from the bottom of the separators. In lubricating-oil sludge, steam must be employed to effect separation, several hours being necessary for "cooking" or "steeping," before the layers of acid tar, acid oil and aqueous 30° acid separate sufficiently to be removed.

suction when the clean-out openings are uncovered. During the natural process of concentration only natural draft is provided.

Weak sludge is fed into this apparatus through a distributing tank and is concentrated in this first stage to 57° to 61° Bé. The strength of concentration depends somewhat on the type and nature of the sludge, as the separation takes place at slightly varying strengths, according to the kind of sludge used.

Second stage.—The apparatus for the second stage is similar to that used in the first. After the acid has been allowed to stand in separating tanks for a period long enough to accomplish satisfactory separation, it is drawn off and elevated to a distributing tank located on the top of a preheating tower. A flue, connected to this preheating tower is so constructed as to accommodate a bath of acid.

It is to be remembered that this acid, as it enters the preheating tower, is from 57° to 61° Bé. Further and final concentration takes place in this unit, which is almost identical with the first stage unit.

Ordinarily the acid is concentrated at 66° Bé., although the process has accomplished concentration in this unit as high as 95 per cent.

The gases leave the preheating tower at about 160° F. and, of course, carry sulphuric acid fumes. For this reason a scrubbing tower is provided for the purpose of reclaiming the acid from the fumes. The gases leave the preheating tower at the top and enter the scrubbing tower at the bottom. The scrubbing tower is packed with spiral rings to provide intensified mixing and scrubbing. The gases leave the tower free from sulphuric acid contents and enter the atmosphere through an exit stack. Clean-out openings are provided in this unit, as well as in the first stage unit, together with coolers and strong acid intermediate storage.

General.—This apparatus consists principally of lead-lined wooden tanks and acid-proof masonry flues and preheating towers, together with lead scrubbing towers, lead-lined distributing tanks, etc.

The first stage and second stage units are very similar in construction and consist principally of a brick-lined lead basin, elevated above the ground on concrete foundations. At one end of this basin a brick tower of sufficient size and height is provided for preheating; connected to this tower and covering the balance of the basin, is a brick flue through which the acid-proof hot-air supply pipes enter. Ample provisions are made for cleaning and regulating the apparatus during operation.

Hot air is provided, preferably by the combustion of oil which takes place in the specially designed combustion furnace, under pressure. This furnace is fed with air and fuel oil sufficient for complete combustion and also with sufficient surplus air for heating purposes.

With the above-mentioned process, hot gases, on entering the liquid below the liquid level, are suddenly cooled, in such a manner as to prevent any dissociation. The concentration takes place below the boiling point of the acid. Futhermore, the plant is so constructed as to provide continuous operation, and as practically all the heat units are used in the evaporation of water, the fuel consumption is exceedingly economical.

In addition to the more important types of special refining processes recently discussed, there are others, such as the recovery of alkali,[1] the commercial utilization of the petroleum and naphthenic acids present in sludge,[2] the employment of various chemicals to obtain certain objectives,[3] etc., all of which are of potential, if not of present importance. Lack of space prevents their discussion.

[1] For a condensed description of several methods, proposed and in practice, for recovering alkali, see American Petroleum Industry, II, 1916, 592.

[2] Ibid. Russian refiners claim to have produced driers and substitute resins for varnish-making purposes, electrical insulating compounds, soap fillers, etc., from sludge acid residues. The manufacture of chewing gum from certain naphthenic sludges has been proposed in this country.

[3] Various patents and processes have been proposed from time to time for refining petroleum

For a like reason, as well as because such processes are of a synthetic rather than of a refining nature, a description of the manufacture of translucent soaps, pastes and cutting compounds, castor oils and gelatine, greases, etc., however interesting, are beyond the scope of this chapter.

IV. PREVENTING AND EXTINGUISHING FIRES

The importance of fireproof construction and the maintenance of certain proportionate distances between refinery buildings and tank units in their relation to fire prevention has already been discussed in an earlier section[1] and fire-fighting equipment has also been covered in some detail. When it is considered that nearly 62 per cent of all oil fires are caused by lightning,[2] the reason for such construction and equipment is the more apparent.

On the other hand, particularly in the more complete refineries and in districts where lightning is comparatively rare, statistics show that a considerable proportion of fires are the result of carelessness in operation. The following suggestions are offered for fire prevention.

Operating Suggestions for Prevention of Refinery Fires[3]

Lighting fires.—Carry no matches of any kind into a refinery, unless the work calls for their use. In any case carry only safety matches; a fall, or contact with a hot line, may easily ignite the standard match with possibly fatal results to the operative.

Do not attempt to light any oil or gas burner with which you are unfamiliar, or to light any burner without first turning off the air mixer or steam valve, or without first opening the damper. Adherence to this rule will greatly lessen the danger of burns and back-fire explosions.

Use a waste torch, with handle at least 3 feet long, when lighting any gas or oil burner (laboratory bench apparatus excepted), and avoid serious burns. Never drop lighted matches or waste torches on the ground without first extinguishing them. Provide an extinguisher well for the torch and avoid fire risk, and have the torch always ready for use. Avoid standing directly in front of fire doors, when lighting a fire; back-flashing often occurs, and results in serious burns.

Be sure a still is charged or charging before starting to fire. Failure to observe this precaution has caused terrible explosions with attendant loss of life and property. Never fire any still after it has stood charged for any length of time, unless the bottom has been examined for excessive leakage. Back-firing is very likely to occur if any amount of oil has accumulated under the still.

Avoid standing near any fuller's earth or bone-char kiln door, until the feed is working regularly. The greatest danger of back-flashing occurs when the earth or bone char first starts through the kiln. Do not light any welding torch unless the oxygen stream is turned off. Serious burns may otherwise result, especially in a

products, employing lime, baryta, and aluminum hydroxide. Treatment with metallic sodium has also been suggested, as well as various salts of alkali and alkaline earths; also those of iron and copper. As far as is known, such processes are not employed commercially in American practice. A condensed description of the class just enumerated may be found in American Petroleum Industry, II, (1916), 606.

[1] See p. 84.

[2] According to statistics published by the Bureau of Mines (Bull. 170, 1918), 61.8 per cent of the oil fires, from 1908 to 1917 inclusive, were caused by lightning.

[3] The series of articles entitled "Cautions and Don'ts for Refiners," originally published by the author of this section in the Oil News, 7, 22, 1919; 8, 3, 1920, and 8, 20, 1920, has been freely drawn upon in the preparation of this article.

confined space. A parting caution—light no match, waste, torch or other free flame except where absolutely necessary. There is always a distinct element of danger in their use.

Pumping.—Observe warnings given under " Lighting Fires"; this course will prevent many a conflagration and perhaps fatal accident. Remember that if there is any one thing about refinery operation which is not understood it is the extent to which a fire may spread, however insignificant its start.

Before attempting to pump any oil, first ascertain by gage whether there is room for the transfer; second, make sure that valves and lines have been properly inspected. Spills or overflows are costly and generally inexcusable and are the starting point of many a fire.

After starting to pump, follow the line from end to end and ascertain whether the oil actually flows where intended. A close adherence to this rule will prevent much loss of oil and lessen the fire risk. Many moderate-sized plants could profitably employ a line walker.

After pumping is finished be sure to close all valves. This is the only safe rule for protection against mixes, flowing together of tanks, or spills.

In general, make frequent inspections of the packing of pumps, lubricators, rocker arms, etc. The failure of these in time of need may be responsible for the spreading of a fire which would otherwise be easily checked.

Stilling.—Before pumping to stills, observe the following precautions:

(*a*) If stills are new, inspect caulking inside and out, sound suspected rivets, and test under 10 pounds water pressure. Do not charge if leakage or stress is evident, for reasons that are obvious.

(*b*) If previously in use, inspect bottoms externally and internally at regular intervals, the length of which will depend on the nature of the product run, and always after bringing down to clean. Sound suspected thin spots with a 2½ pound hammer, and cut out and patch springy spots.

(*c*) Inspect coke stills after every run, sounding bottoms carefully, and observe metal for burned or brittle spots. Avoid removal of coke burned into seams, but clean well over rivets. Systematic still-bottom inspection is a very effective form of fire insurance.

(*d*) Occasionally inspect vapor lines of coke stills, particularly if they are insulated to towers. Coke has been known to accumulate, remain hot from previous run by slow oxidation and ignite subsequent charge of crude with a violent explosion.

(*e*) Ascertain that all manplates are plated up, and bolts or bars drawn tight. Particularly note end necks for leakage when charging. If leakage occurs, tighten before firing; if it is impossible to stop, pump out the still and replate. A leaky manplate sometimes takes up, but more often does not. It ultimately ignites, and frequently becomes uncontrollable with great danger of a disastrous fire.

(*f*) Determine that all valves or cocks, steam, flow, pumping-out and especially safety and vacuum valves are in order, and that safety and vacuum valves are set properly.

(*g*) Be sure that the gage column is clear, and that a wire can be freely passed through upper outage pet-cocks. Do not assume that a still is properly charged; see that oil shows at the proper cock, and not at the one immediately above. The safe operation of a plant depends on adherence to this rule, and it is an excellent plan for two men to verify the gage.

(*h*) In the case of a hot still, be sure that a small amount of top steam is cut in and try the vacuum valve frequently, opening up full on the line only after the vacuum valve begins to act sluggishly.

After firing stills be sure of the following points:

(*a*) Cut the still in the house to the slop tank, and see that the still gas is turned into the gas line.

(*b*) See that the water trap in the run-down line is clear and working freely. A broken fitting, quite possible in cold weather, may mean the loss of considerable oil with danger of fire, if breaks occur on the light end of run.

(*c*) Go over the mannecks carefully for loose bolts after one hour's firing and tighten immediately if a leak develops. Trouble begins only if the neck catches fire.

(*d*) Try water draw-offs, coil or preheater (according to refining method used), for water. On continuous charging attend to this frequently. A blowing still means loss in yield and in profit, and may mean a fire.

(*e*) When bringing in a still keep in touch with the progress of the operation by feeling the dome, vapor line, or tower, at intervals depending on the size of the still, the amount of heat and the nature of the product. Slack the fire before bringing the stream into the receiving house, and be sure that the condenser is full of cold water. These precautions will avoid costly blows and fire risks, particularly on fresh gassy crudes.

(*f*) Whether the internal (oil) temperature of the still is determined by thermometer or pyrometer (indicating or recording), or by the old method of letting the still settle down to boil, be sure that the correct temperature is reached before the introduction of steam. Admit the latter only after blowing off carefully, gradually slackening the fire in the meantime if on light oil. A "puking" still [1] is a dangerous proposition, and is impossible if proper care is used in cutting in steam that is properly piped with adequate water separators.

(*g*) Never neglect to inspect the steam valves carefully, even after steam is admitted. A loose-stem globe valve will gradually work open, with possibly dangerous results.

(*h*) When taking samples be sure to leave the wrench on the sample cock so as to be able to close immediately in case of need; and do not hold the face close to the sample pan. Ignition often takes place, and a painful burn or loss of sight may result.

(*i*) If operating continuous stills, check the levels against the gravities of stream, at least hourly; and when cutting a still in or out of circuit, watch the flow lines carefully and be sure of valve control. A valve stem may stick and occasionally twist off at the high temperatures involved. Failure to provide for this, or careless handling of flow lines, may have very serious results. Remember that you are dealing with hot oil which will flash in open air.

(*j*) Finally, inspect the bottoms frequently for dark spots and leaks at seams or rivets. Just when it becomes necessary to drop a still on account of these defects, is easier to determine from observation than to describe; but it may be noted that the best time to gage a hot bottom is about fifteen to thirty minutes after the fires have been pulled. Dark spots stand out very clearly at this time, and dangerously dirty bottoms can readily be detected. No still, however clean it may appear, should be run any great length of time without internal inspection. Take no unnecessary chance, and avoid possible fires.

[1] The word "puking" is expressively used in refinery parlance to denote the boiling over of a still, in which the crude charge mixes with distillate and generally contaminates the contents of a run down tank. As this action is more likely to occur during elimination of entrained water, a still is invariably cut to the slop tank when first brought in, thus avoiding any danger of contamination at this point. Improperly applied steam will also cause "puking," hence the caution above. With certain viscous oils or heavy crudes, a still has been known to empty itself before it could be controlled; and where (as is sometimes the case) the mixture of crude and vapor is evolved faster than the worm or run-down lines will carry it away, discharge through the top manplate usually takes place, very frequently accompanied by a serious fire.

When bringing off stills, note the following points:

(*a*) Do not neglect to try gage cocks frequently during the latter part of the run. Bear in mind that the volume per inch rapidly lessens as the level in the still drops, and thus avoid coking or burning of bottoms.

(*b*) If running to coke, have the fires well in hand at the first showing of gum or tailings, as their appearance is a sure sign that the still is about ready to coke. Exceptionally close attention at this point is essential to safe operation.

(*c*) When the level is about down to gage or the required flash or viscosity is reached, see that there is sufficient water in the pumping-out pan and that the pump lubricators are filled. A broken pumping-out line has caused more than one fire, generally because the equipment was not in first-class condition.

(*d*) After fires are pulled and before actually turning into the pumping-out line, make sure that there is sufficient steam entering the still to guard against vacuum and possible internal explosion.

(*e*) Start the pump so that there will be suction in the pumping-out line before turning the oil into it. This will prevent possible ruptures of the line or blow-back into the still, should water lie in the condensing coil.

(*f*) Open the pumping-out valve carefully so as to heat up the line gradually and take care of expansion. The tar plug, in the meantime, should have been raised and supported by an easily dislodged prop (preferably of wood) so that in case of an emergency, instantaneous closing can be effected. A tar plug which is difficult to open or close is of no value in fire protection; frequent inspection is therefore necessary.

(*g*) After pumping out, do not unplate without adequate steaming and cooling. Many accidents, varying from slight flashes to violent and disruptive explosions, have been caused by premature stripping.

(*h*) Never enter a still immediately after unplating. Allow time for additional ventilation and cooling, and in no case carry any free-flame torch into a still or allow hot work to be done on it until the still is throughly clean and cool.

(*i*) Even then, attempt no repairs before ascertaining that there is no chance for gas to back into the still from the vapor line or other opening. If oxy-acetylene cutting is to be done be especially careful to see that the still is extra clean. A flash has been known to pass along the seam of a carelessly cleaned still, causing serious burns to the repair gang, all of which could have been avoided by proper care.

In short, fires and accidents can only be prevented by strict attention to details. If this course is necessary on standard stills, it is doubly so on those of special design.

(*a*) Tower stills, for instance, generally run under a pressure 2 to 5 pounds greater than that employed in the standard still, and leaks which are negligible in the latter type are dangerous to the former.

(*b*) Frequent inspection of run-back lines to the still, especially if they are fitted with traps, is essential to safe operation. If any quantity of condensed oil accumulates in a tower, and later suddenly finds vent back to the still, it will cause a violent blowing off and will frequently produce sufficient pressure to cause a strain on the plate and rivets, invariably producing dangerous leaks.

(*c*) Steam-still vacuum valves need especial attention. A sudden cutting off of steam supply, particularly when heavy naphtha is being run off, may easily cause collapse if the vacuum valve is not in free working order.

(*d*) Pressure stills are so specialized in their operation that cautions peculiar to each individual type must be employed, although many of the general cautions given can be used to advantage as well. Attention is called, however, to the rapid decline in tensile strength of steel at elevated temperatures, values being as follows:

At 400° F. tensile strength is still 100 per cent.
At 500° F. tensile strength is only 98.5 per cent.
At 600° F. tensile strength is only 95.5 per cent.
At 700° F. tensile strength is only 68.0 per cent.
At 800° F. tensile strength is only 44.0 per cent.

The danger from overheating, of course, becomes apparent at once, and further comment is unnecessary.

(*e*) In general, while the application of the above suggestions will cover the usual operative conditions incident to handling stills, there will always be emergencies requiring the best judgment of the stillmen. Here quick decision and immediate action are highly valuable assets toward fire prevention.

Treating.—In the process of treating, the chief danger from fire occurs through ignition of the gases immediately above the oil (assuming that the treating is conducted in the well-known type of agitator), it may be said that danger is limited almost entirely to the lighter products, such as gasoline, benzine and burning-oil, although certain heavy products are sometimes treated at high temperatures, thereby adding an additional risk.

Ignition is invariably due to one of the following four causes, listed in the order of their frequency:

(*a*) Electrical discharges.
(*b*) Chemical action. (Ignition due to this cause is often erroneously attributed to spontaneous combustion.)
(*c*) Friction.
(*d*) Self-ignition due to the high temperature employed. (Occurs rarely and then only on heavy reduced crudes, dry-run tars, etc.)

(*a*) Ignition from electrical discharges may be due to static or frictional electricity of extremely high voltage, induced by friction of belts, pumps, flow, etc., and discharged from some entering line to the shell of the agitator. It is usually more manifest in dry cold weather, and can be guarded against by properly grounding all discharge lines to the agitator. Grounding should be tested for resistance, and ground wire should penetrate the soil to a sufficient distance to insure electrical dissipation, preferably to water, where possible. Clamp connections for attaching ground wire are unreliable; only soldered joints should be used and special care should be taken if the motive power of the blower is electrical.

Electrical ignition may also be caused by faulty wiring, the use of non-vapor-proof globes, receptacles, etc. Proper installation of wiring system and frequent inspection of the latter as to grounds, poor conditions, etc., are the obvious remedies.

(*b*) The chemical causes of ignition, while somewhat obscure, can usually be traced to the presence of sulphur in the distillates handled, principally in the form of hydrogen sulphide or some organic sulphide. Such sulphur-containing vapors react during agitation with the iron of the agitator and form ferrous sulphide, which under certain conditions oxidizes rapidly to ferrous sulphate, with a dangerous rise in temperature. The hydrogen sulphide component in the vapor may also react with sulphur dioxide gas produced during treating and deposit elementary sulphur, which in turn under suitable conditions of heat and moisture may form ferrous sulphide with the evolution of sufficient heat to produce a glow or hot spot in the metal. Very probably both reactions take place simultaneously in actual practice. While this explanation is of interest the resultant facts are more important, and may be summed up as follows:

If an explosive mixture of gases be present in an agitator at the time of hot-spot formation of sufficient temperature for ignition, the inevitable occurs: an explosion

or fire results, its intensity depending on the composition of the vapor immediately above the oil. It follows, therefore, that anything which will lessen the tendency to hot-spot formation will aid in the prevention of fire, the following measures serving the purpose to a greater or less extent:

(1) The lining of all iron surfaces with sheet lead, on which sulphide compounds have little action (except the formation of a thin film of lead sulphide), serves as the best preventive.
(2) In unlined agitators the frequent washing and removal of sulphur deposits is of benefit.
(3) The use of protective paints on the inner surface of the roof may serve in certain instances, although this is not very dependable.
(4) The use of draft flues to carry away the gases evolved during treating is practiced where a large volume of sulphur products is evolved.
(5) The use of a small amount of steam to render the vapor less explosive is often employed with success in treating gasoline, benzine, etc.
(6) The substitution, in certain cases, of wooden roofs. This is not ordinarily justifiable on account of fire risk, and does not always prevent ignition, presumably on account of the iron nails employed. It has been tried out with some success in the handling of high sulphide-bearing distillates, but is not recommended.

(*c*) Ignition from friction can obviously occur only where friction is possible; hence t should be ascertained that no loose lines enter the agitator and that revolving sprays, :f used, are free in action and kept in first-class working order. No chances should be taken where metal can strike metal. A spark may not be produced once in a thousand times; the thousand-and-first contact may prove very disastrous.

(*d*) Self-ignition can only occur where products are treated at too elevated a temperature, and a fire from such cause is invariably a result of violation of a direct order. As a safe rule, attempts to treat any dry-run tar or reduced crude above 300° F. should be avoided.

In general it should be noted that the explosive limits of a mixture of petroleum vapor and air are comparatively narrow, and that when ignitions do occur they are often simply flashes passing through the gaseous mixture above the oil without results other than a very slight explosion, especially when explosion doors fall closed, so that it obviously follows:

(1) That all explosive doors should be so constructed that they cannot be fastened back and will close practically gas-tight.

(2) That there be a sufficient number of doors to exhaust the force of the severest explosion without injury to the shell or roof of the agitator.

(3) Inasmuch as the force of any explosion is dependent not only on the composition of gases, but on the actual volume of gas present, it further follows that all treating should be conducted with the agitator as full as possible for practical handling, thereby cutting down gaseous space and lessening disruptive effect.

A persistent disregard of this caution, results sooner or later in an explosion, probably because the increased vapor space affords a better opportunity for the production of a perfect explosive mixture of gases (thereby causing ignition, which would be impossible in a rarer mixture. If the outage is considerable, and the agitator constructed with insufficient explosion doors (the usual type of fabrication), the disruptive effect is often great enough to blow the roof of the agitator to a considerable distance, with an intense fire almost immediately ensuing. As a fairly safe procedure, do not treat with an outage over 6 feet.

Another point of danger is the lower part of the shell below the cone, usually a closed space with one or two entrance doors at the most; otherwise unventilated. Here an explosive mixture of gases usually exists, and is a constant fire menace in many plants. Guard against explosion and fire, save waste and add to the general neatness and clean lines by observing the following precautionary measures:

(1) Inspect lighting system frequently and under no circumstances use other than vapor-proof fixtures with a switch outside of the agitator.

(2) Keep valve stems packed and gaskets tight and in general, prevent leaks around distributing manifolds; absence of drips means absence of gas.

(3) A leaky agitator body, aside from the danger from gas formation, means waste; keep it tight.

(4) While a sewer lateral should run from the lower part of the agitator directly under the cone, to carry off leakage, waste from try-cock, etc., the main wash line should extend outside of the agitator into a sewer large enough to allow no chance of oil or water backing up under the cone. Such construction will avoid any possible chance of discharging a large quantity of oil under the cone and will prevent the formation of vapors.

(5) Keeping the agitator sewer open by cleaning at regular intervals, and provide with traps before cutting into the main sewer or separating basin.

(6) Cut apertures in the outer supporting shell close to the base of the cone for ventilation, and avoid the accumulation of gas.

(7) Keep the floor beneath the cone tight and in first-class condition, sloping toward the sewer so that if leaks actually do occur the product will be carried off with a minimum of vapors arising from stagnant pools.

(8) While actually treating, avoid any repairs which involve striking of metal where a spark might cause ignition of vapor.

(9) Provide entrances with doors that are reasonably tight and equip the space below the cone with a steam fire line as a further preventive.

As an additional preventive against the spread of fire, some refiners adopted in the past a so-called fire suction, in the form of a line of large capacity extending up the side of the agitator to within a distance of about 4 feet from the top of the shell. In case of fire, water was pumped into the bottom of the agitator, forcing the oil to rise and be taken away by a fire suction line, so that serious damage was done to the top and roof of the agitator only. The use of the fire suction line as a preventive against the spread of fire and damage to equipment has, however, been almost entirely supplanted by foam installations, which will be presently discussed.

A word as to acid, alkali and other chemicals used in treating: note that concentrated 66-degree sulphuric acid chars wood, and that dilute acid dissolves many metals, with a simultaneous evolution of hydrogen gas; that sulphur is moderately combustible; that both strong acid and caustic when mixed with water produce a considerable rise in temperature. The danger that fire will be directly or indirectly caused by the chemicals usually used in treating is admittedly remote, but it exists, nevertheless. Therefore, do not allow acid drips, and keep each chemical in its proper bin or location. If nothing more is accomplished than the prevention of waste, this alone will repay any extra attention to these items.

Finally, special methods of treating involve their own peculiar fire hazards, and must be handled accordingly. Among these methods may be mentioned the continuous process, essentially a process conducted out of contact with air, the treating of hot reduced crudes or tars at high temperatures, the employment of fuming acid or sulphuric anhydride direct as is practiced on oils of high aromatic content (notably California distillates), the use of liquid sulphurous acid (practically limited to foreign practice), and other special processes which have not been described. All these require

some modification, from a slight change, to the use of apparatus widely different in design from the standard type of agitator.

Filtering.—The danger of fire in filtering operations is confined almost wholly to the process of washing and revivifying the filtering media used, and has as its origin the following causes arranged in the order of their frequency:

(*a*) Ignition of benzine or naphtha vapor evolved during washing or steaming of filters.

(*b*) Ignition of benzine or naphtha vapor evolved from imperfectly steamed filtering medium.

(*c*) Ignition of oil vapors evolved from imperfectly washed filtering medium.

(*d*) Ignition of combustibles other than vapor or oil, through the agency of the revivifying retort.

(*e*) Ignition of combustible material through friction of the conveying machinery.

(*f*) Ignition of benzine or naphtha vapor, evolved during washing or steaming, is of somewhat frequent occurrence, and often leads to serious fires and fatal accidents. It may be guarded against by the following preventive measures:

(1) Do not locate the filter house too close to the revivifying apparatus or to any other source of free flame. Most vapor ignitions are caused by contact of escaping gases with the free flame or fire in the revivifying apparatus.

(2) Avoid all unnecessary windows and doors in adjacent sides of revivifying and filter houses, so as to avoid currents of gas.

(3) Frequently inspect the condition of valves, cocks, manplates, etc., where gas or liquid naphtha may escape; also wiring, globes, etc.

(4) Equip all filters with two safety valves, one set at 10 pounds above the other, the second to act as an emergency valve; valves to be of enclosed pop type and provided with lock control over spring set.

(5) Connect safety valves to separate vent lines extending outside of building on the side away from the revivifying apparatus—at least 200 feet from any free flame, better 500 feet.

(*b*) Fire sometimes occurs in the preheating bins, the retort or revivifying apparatus because the filtering medium (fuller's earth or bone char) has not been properly steamed and is not entirely free of its naphtha wash. Such material often generates a gas through contact with the heated walls, or through too rapid feed to the retort, so that the charge becomes prematurely ignited. Sometimes the ignition merely amounts to a puff or explosion, self-extinguishing in nature; but at other times the result is a fierce flame, which is often difficult to extinguish, and may damage roof, bin and platforms extensively. The remedy is obvious—never discharge spent earth from filters for reburning, unless it has been properly steamed.

(*c*) An imperfectly washed earth may be steamed fairly free from naphtha and give trouble all along the way, from a fire in the green bin to an explosion in the filter in packing, especially if bone char is the material used; hence imperfectly washed earth should never be delivered to the retort or kiln, as trouble is thereby invited.

(*d*) The ignition of inflammable and combustible material, other than vapor or oil, through the agency of fire in the retort or kiln, may be avoided by a precaution so obvious as not to require mention. It is simply this: keep such material away from the retort or kiln where hot coals, ashes, or hot burned earth or bone char can come in contact with it. In other words, have fireproof construction. This is particularly necessary where bone or blood char is used, as these materials, under certain conditions, may absorb oxygen rapidly enough to burst into flame, more than one fire having started in this manner. A few explosions have resulted from obscure causes, probably from the presence of fine dust in the air. In the case of fuller's earth, this dust, while a disagreeable feature, is not actually dangerous; with bone char, however, an explosive

dust may easily exist. Hence the accumulation of such material should be avoided by suitable screens.

(e) The last cause of fire about a filtering plant, retort, or kiln is a remote one, but must nevertheless be considered. Bearings quickly become dry in a dusty atmosphere, and failure to lubricate conveying machinery properly may cause sufficient heating to ignite conveyor belts, etc.

As a final caution be particularly careful to inspect wiring where hot filtering is a part of the process. Have a systematic scheme of frequently testing out safety-valve blow-off lines to see that they do not become clogged with earth or bone, and thus become useless. Finally, it is very important to see that the wash line to the wash still is open before starting a wash.

Wax separation.—The element of risk in this part of the process is generally remote, as buildings containing refrigerating equipment are usually substantially built and are of more or less fireproof construction even in the older refineries. Moreover, the products handled are of comparatively high flash and fire test. Certain fire hazards exist, however, and while remote are within the scope of this article.

(a) Explosion or fire caused by ignition of mixtures of ammonia gas and air.

An explosion of ammonia gas and air is a comparatively rare occurrence and the risk from this source is practically negligible in an absorption plant. Under certain circumstances, in a compression plant where purging has not been properly attended to, or lubrication has been neglected, sufficient heat may be generated in compression to cause ignition, thus causing one of those mysterious explosions which are so difficult to explain. Avoid such an accident by proper purging and lubrication and, in general, do not use a free-flame torch around ammonia gas.

(b) Explosion or fire caused by ignition of mixtures of ammonia gas and gaseous hydrocarbon impurities present, i.e., purging gas.

Ignition of purging gases only occurs when a free flame or defective wiring (an electric arc) comes in contact with the gases. As these are invariably blown off in the open the danger is a slight one, and the method of avoiding it is self-evident.

(c) Explosion or fire caused by ignition of mixtures of oily vapors and air, produced when melting up " slack " wax.

Explosion or fire caused by vapors given off during " slack " wax melting is also easily avoided. Keep free flame away and wiring in good order and, in general, wherever there is insufficient space about a wax plant use vapor-proof globes.

Shipping.—Under the head of shipping may be considered the loading of tank cars, barreling, canning, and the various operations incident to preparing petroleum products for the market. Fires may originate at a loading rack from any of the following causes:

(a) Ignition from sparks of passing locomotives, or hot cinders discharged thereby.

The menace from passing locomotives is not serious, as no attempt at loading is made in any well-organized plant when switching is taking place; but occasionally a loading rack is perforce located close to a main line. The writer recalls one instance in which a spark from a fast main-line train dropped squarely into a car loading gasoline on a siding some 90 feet away. Fortunately, the result was only a fire, and not an explosion. Of course, loading should be absolutely prohibited when switching takes place, and the rack located as far from the main line as possible. When it is dangerously near, use galvanized covers for gasoline and light oil punched to allow loading lines to pass, and avoid the chance spark.

(b) Ignition by discharge of static electricity from loading lines, caused by electrically driven units, belt friction, etc.

All electrical discharges can, of course, be easily prevented by proper grounding; but even when lines are believed to be so protected, it is well to test them with an

electroscope when pumping is taking place and to determine their condition once and for all.

(*c*) Ignition by spark produced by frictional means when shifting loading lines, etc.

A spark is hardly ever produced by frictional means in shifting lines except by direct carelessness in handling the lines. Avoid such carelessness and prevent the hazard.

(*d*) Ignition from oily waste used to wipe out cars, sometimes spontaneous in nature if cars have previously contained a vegetable oil, such as cottonseed.

If oily waste is never allowed to accumulate, this source of danger is removed.

(*e*) Ignition from a free flame, perhaps a railroad lantern too close to a leaky car.

It goes without saying that lanterns, free-flame torches, etc., should never be used about a loading rack; this applies to railroad men as well as to refinery employees. Absolute insistence on this rule removes one great source of danger.

(*f*) Gaseous ignition from casing-head gasoline, vapors being carried a considerable distance in the direction of a free flame, such as a still fire, and then flashing back to car.

Danger from gaseous ignition is well-nigh a thing of the past, since all casing-head products are now weathered to a fair degree of safety before loading. Racks, however, where this commodity is handled should be apart from all others, and extra precautions should be used in pumping.

In the barreling of oil or gasoline, previous warnings as to defective wiring, lanterns, etc., should be remembered. It should also be noted that the barrel paste paints used in this end of the industry are usually thinned with naphtha and are highly inflammable, and all careless handling should be avoided.

In the canning department there is always danger from the gas flames used in heating the soldering irons. Brooms are usually very much in evidence in this department; and as they are used for sweeping away oil from leaky cans, and are oil-soaked, they add to the fire risk. Great care should be used in the canning end of the industry and plenty of standard fire-fighting equipment, such as sand, foamite pails and chemical engines, should be at hand.

Another danger that sometimes occurs in the shipping end of the industry is the handling of paraffin wax in cake form, protected by burlap bags. In extremely dry, cold weather, frictional electricity is sometimes developed to an astonishing degree in the ordinary handling of this material, the outer burlap wrapping making excellent tinder for the frictional spark; and in an incredibly short time fire has made serious headway. The remedy is to handle the cakes carefully, and, as far as possible, to avoid shifting them in dry cold weather.

There are other minor points in connection with the shipping end of the industry to which attention could be called. For that matter, considering the subject in general, the writer acknowledges many omissions. Some cautions have been purposely omitted as beyond the scope of this article, others as too self-evident, while still others, probably evident to many a refiner, have simply not occurred to the writer, as he frankly admits; but it is believed that the principal points of fire prevention in refinery operation have been covered.

The fire hazard incident to refinery operation may be considerably reduced by systematic preventive inspection,[1] this being usually combined to advantage with inspection with a view to accident prevention. In fact, the two are more intimately connected than might at first be apparent, for if any operative suffers personal injury,

[1] The article immediately following has been largely taken from "Systematic Inspection," published by the writer in Nat. Pet. News, Oct. 13, 1920.

he must be replaced by a substitute, presumably less skilled (a distinct material fire hazard if process men are involved); moreover, an obscure and imperfectly understood psychological effect has been produced, often undermining the nerve of perhaps one or possibly a score of witnesses. Thus a more dangerous hazard is introduced than the physical absence of the injured skilled operator. Therefore, any form of accident about a refinery is a fire risk, and systematic inspection with a view to the prevention of accidents is a decidedly important branch of fire prevention. A systematic inspection must be understood to involve the making of a daily written report.

The excellent work of the insurance rating bureaus, the suggestions of their trained engineers, together with the accumulated experience of the practical refiner, have all worked towards making the modern refinery a far cry from the fire-trap of twenty or even ten years ago; guards have been placed around machinery, and open gears have disappeared. But the monthly visit of the insurance inspector, the semi-annual trip of the factory inspector, and even the daily passing of the superintendent through the plant, with his mind full of many problems, is insufficient protection in any plant of large or even moderate size.

Some of the large plants employ a fire marshal, and in the extensive eastern manufactories the "safety first" inspector is a fixed institution. As far as is known, however, comparatively few refineries have a system including a form report that gives a complete daily written record of the status of the plant from the standpoint of fire and accident hazard.

To make such inspection a success, the man chosen for the position of inspector must possess keen powers of observation, and should preferably have had some experience in refining and construction. Above all, he must be absolutely honest and fearless in the discharge of his duty.

In the system developed by the writer, it was found advisable to make out two reports, one on the condition of fire-fighting equipment, the other on hazards, one man being able to look after both with comparative ease. The form reproduced herewith, i.e., "Daily Report, Fire-Fighting Equipment," can be very readily covered in the average plant of 4000 to 8000 barrels daily crude capacity, covering 100 to 150 acres, in the course of two hours or so, depending, of course, on the nature of the equipment maintained.

In the plant in which this form of report was first developed, a considerable amount of so-called miscellaneous fire-fighting equipment was listed. An exact count was made daily of several items which might not be deemed necessary by many plants, and the omission of which would obviously shorten the inspection period. In the case cited it is believed, however, that the daily count did not a little in checking the disappearance of sundry buckets, shovels, approach planks, etc., that possess varied uses apart from fire fighting.

With the form before one, it hardly seems necessary to point out that foam solutions must be at full strength to be efficacious, that an empty chemical extinguisher is not of immediate value, and that time lost in hunting for shovels, picks, sand buckets, etc., in time of need, may mean the spreading of a disastrous fire. Instances have been known in which a perfectly good reel of 500 feet of hose was unavailable until a dray had been pulled away from before the door of the hose house. Again, a fire pump has been known to require an hour (or a period that seemed like an hour) to start. All such features have been covered, it is hoped, in the form under discussion, which is self-explanatory to any refiner, except that the terms valve forks, cock wrenches and approach planks may be a little obscure.

The first-named (valve-forks) are long T-handled $\frac{3}{4}$-inch rounds with a two-pronged fork at the end, capable of entering the usual valve wheel; they form admirable contrivances for reaching valves which are inaccessible from fire or other causes. The cock

wrenches are specially forged socket wrenches with a length of 2-inch pipe for a handle, and are provided with ¾-inch holes at the end opposite the socket, for the insertion of turning bars. Such a wrench can often be used on a pumping-out cock which is otherwise inaccessible.

The last-named item, the approach plank, is used as its name suggests, for throwing across gaps such as the low fire-walls back of stills, to gain access to some cock or valve. These planks merely consist of well-chosen oak, soaked in alum water and provided with chains for throwing into position.

It will be noted that the form shown has been partially filled in, in order that it may be more clearly understood. Other reports may, however, suggest themselves as being more applicable to some particular plant. If the principle of daily inspection is maintained and results recorded, the exact form makes little difference; but too great emphasis cannot be placed on a written report, for observations reduced to writing are invariably given more attention than verbal instructions.

Where a plant is too small to employ an inspector profitably, the superintendent or yard foreman can undertake the work, but from reasons earlier stated such inspection can scarcely be as systematic and thorough as when it is the sole occupation of one man.

It has been mentioned that it was found advisable to keep the accident and hazard report separate from that of the fire-fighting equipment, although they are kept by the same inspector. The form on page 418, entitled "Daily Report, Fire and Accident Hazards," will show the advisability of this system, and will also bear out the statement that the inspector should be a man of keen powers of observation.

It might be added he should possess tact as well, as no department head particularly cares to see his department written up; but on the other hand when it is realized that the inspection is meant for the good of all, very little ill feeling results, and where a conscientious, diplomatic inspector is employed, the operatives themselves often go out of their way to call attention to some minor fault. Once reported, the same defect rarely occurs on the following day, for it is one thing to be told of a hazard, and another to see it in writing, the latter always suggesting a certain responsibility wanting in the verbal order.

It is scarcely conceivable that the inspector will so happen around as to personally note all the fires, spills, etc., which should be noted on the second form; but the evidences of such occurrences are never lacking, and it is a part of his duties to secure all information relative to the same. Here again, a tactful and diplomatic inspector is a decided asset. Even in a large plant it is surprising how little escapes the eye trained for this class of work. The report in question is filled in as a typical example of a day's work.

Consider the results of such an inspection. The railroad which performs the switching service will be notified that it has probably a defective screen in the stack of the switching engine, thus, even if no other action is taken, a written record is at hand as an aid to some future claim. On the part of the refinery, more care will be taken in the matter of weeds, etc. The superintendent will take some action on the reported spill and violation of rules, and attention will be called to certain defective wiring and mushroom-headed tools. Again, the written record is emphasized, it being a silent witness that cannot be easily brushed aside, and it always means quicker repairs and higher efficiency all around.

In conclusion, a plant may be erected after the most modern and fireproof plan of construction it may have the latest and most approved apparatus for preventing fires and a tried system for extinguishing them, if they do occur; it may post an elaborate series of "Safety First" bulletins weekly or semi-weekly; but without a systematic preventive inspection both for fire and accident hazards it has not reached its highest possible efficiency.

INSPECTION DEPARTMENT

DAILY REPORT, FIRE FIGHTING EQUIPMENT

Date......Ju. 3,......192....

Hose House No.	Official Sealed Equipment	Seal No.	Unsealed	Equipment Missing	Doors Free Obstructions	Remarks
1	*Yes*	*234657*			*Yes*	
2	"	*58*			"	
3	*No*		*Yes*	*50' Length Hose.*	" "	*Repairing coupling, will have replaced and sealed.*
4	*Yes*	*59*			*No*	*Load gravel broke down, gang now cleaning up.*
5						

Foamite Tanks	Official Number Service	Solutions at Strength	Leaks	Gage 30 Tank	Gage 31 Tank	Valves Free Obstructions
30 31	*2*	*Yes*	*No*	*10' 3*	*10' 5*	*Yes*

Hydrants	Official Number Service	Connections O. K.	Leaks	Equipment Missing	Plugs Free Obstructions	Remarks
Water	*20*	*Yes*	*At # 7 Small*	*Cap gone # 7*	*Yes*	*Pipe Fitter foreman will send gang to # 7*
Foamite	*3*	"	*None*	*None*	"	

Fire Pumps	Official Number Service	Connections O. K.	Start Readily	Equipment Missing	Valves Free Obstructions
Water	4	*Yes*	*Yes*	*None*	*Yes*
Foamite	1	*1*	"	"	"

Fire Lines	Official Connections	Connections O. K.	Leaks	Equipment Missing	Valves Free Obstructions	Remarks
Water	All Hydrants	*Yes* *Broken Ell*	*Small # 7*		*Yes*	
Steam	All Tanks	*100 Tk.*	*None*		*Yes*	*Notified Pipe Fitter foreman.*
Foamite	All light Oil Tanks	*Yes*	*None*		"	

Miscellaneous	Official Number Service	Sealed Official Location	Condition	Equipment Missing	Free Obstructions	Remarks
Sand Bbls.	*25*	*Yes*	*Full*	*None*	*Yes, except # 13*	*Dray backed up against drum.*
Buckets	*30*	*Yes, except # 5*	*O. K.*	*# 5*	*Yes*	*# 5 Report. bottom # 2 Con.*
Shovels	*36*	*Yes*	"	*None*	"	
Valve Forks	*6*	*Yes*	"	"	"	
Cock Wrenches	*6*	"	"	"	"	
Approach Planks	*6*	"	"	"	"	
Acid Soda Hand Exting.	*20*	*# 2 & 4* *Yes*	*Empty* *Full*	*# 2 & 4 at Lab. for Refilling*	*Yes*	*Lab. promise return # 2 & 4 afternoon*
Acid Soda Chem. Eng.	*4*	*Yes*	*Full*	*None*	"	
Pyrene Extinge.	*6*	"	"	"	"	
Foamite Pails	*12*	"	"	"	"	
Foamite Chem. Eng.	*1*	"	"	"	"	
Blankets	*10*	"	*O. K.*	"	"	

.................*J. D. R.*..........*Inspector*

INSPECTION DEPARTMENT

DAILY REPORT, FIRE AND ACCIDENT HAZARDS

Date............July 3,.................192..

Nature Hazard	Kind	Size or Quantity	When Noted	Location	Whom Notified	Remarks
Fires	*Weeds*	*Small*	*10 A.M.*	*W. Ma. P. Switch*	*J. Dolan*	*Caused by cinder from switch eng. stack —too many weeds*
Spills	*B. Oil*	*1 Bbl.*	*11.45 A.M.*	*Load. Rack*	*W. Johnson*	*Over-run G.A.T.X. 15,350*
Leaks	*None Noted*					
Rags, Clothes, Trash	*Old Shoes*	*1 Pr.*	*2 P.M.*	*# 1 Rec. House*	*L. Jones*	*# 1 Rec. House neater than usual.*
	Rags	*Pile*	*2.30*	*Near Th. 725*	*S. Stevic.*	*Left from wiping tank, will clean up to-day.*

Nature Hazard	Kind	Defective or Dangerous	When Noted	Location	Whom Notified	
Electric Wiring	*Vapor Proof Globes*	*Missing*	*3.00 P.M.*	*# 2 Rec. House*	*J. Monlan*	*Will install at once.*
Fire Doors and Hatchways	*All*	*O. K.*				
Fire Walls and Dikes	*All*	"				
Ladders and Walkways	*All*	"				
Machinery and Tools	*Cold Cutter*	*Mushroom Head*	*4 P.M.*	*Boiler Shop*	*L. Tenant*	*Will reforge early to-morrow*
Gen. Construction	*None going on.*					

Violation Rules	Kind	By Whom	When Notified Noted	Location	Whom Notified	
	No Smoking	*P. Czernic*	*4.20 P.M.*	*Still cleaners Shanty*	*L. Hicks*	*New man, thought all right light up before out of gate*

......................................*Inspector*

Extinguishing Fires

In extinguishing refinery fires, aside from the small portable hand extinguishers,[1] often highly efficient with incipient blazes, the chief weapons of the refiner are water, steam, and frothy mixtures.

The use of water, however admirable for ordinary conflagrations, is generally unsuited for extinguishing oil fires. It is difficult to cool below the burning-point, any large open, flaming mass of oil by the use of water, and as the two liquids are not miscible, the

[1] The acid soda type of extinguisher, familiar to all, and the small force pumps containing carbon tetrachloride, give excellent service, as do also the pail containers of frothy mixture producing chemicals. Sand, and even fuller's earth, have been successfully used in small blazes, and for laboratory use and incipient top manplate fires, these common materials are preferred by many.

smothering effect that the steam would ordinarily produce is wanting to a great extent. In fact, if the body of oil is large, the use of water is a dangerous practice, for the burning oil will float on the water and may be carried to a considerable distance along drains, pipe trenches, etc., spreading fire in its path. On the other hand, the direction of several streams of water against the sides of a burning tank, where a frothy mixture is being applied, will often serve to protect the metal so that the tank may be used almost immediately with slight repairs. When a fire has been extinguished by a frothy mixture, and glowing embers still persist, water, judiciously used, will complete the work of the foam solution; but its principal use in refinery fire-fighting must always be the cooling of walls, lines, supports, etc., that would otherwise collapse from excessive heat, rather than the extinguishing of the fire itself.

Before the general advent of froth-producing mixtures, the refiner placed his chief reliance on steam as a means of extinguishing fires, and where steam can be applied in a confined space its results leave nothing to be desired. The function of steam is simplicity itself: it displaces the air, and, with no oxygen present, the fire at once begins to die down and shortly becomes extinguished. Unfortunately in most so-called confined areas there is generally a sufficient draft (caused by broken windows, open traps, tank roofs which have been displaced by explosions and so raised or buckled, etc.) to prevent complete displacement of air, with the result that steam cannot always be depended upon to extinguish an oil fire. It is particularly unreliable with light, gaseous, volatile products. It should be understood that the application of steam, even under somewhat unfavorable conditions, is often attended with success; but this does not alter the fact that complete dependence cannot be placed on it, and that in open areas, such as a burning tank or agitator from which the roof has been entirely dislodged by an explosion, or by the burning away of supports, steam is of comparatively little value, and resort to frothy mixtures is the only solution for extinguishing the blaze.

A description of the so-called "foamite" system has been given in an earlier section.[1] Other systems making use of froth-producing mixtures are employed, however, the essentials, aside from the mechanical equipment, being two chemical solutions that upon being united, produce a thick, tenacious, lasting foam which spreads freely over the surface of the burning oil, thereby excluding air and extinguishing the flame.

In general, the solutions for producing foam may be any two mixtures which on uniting form a large volume of relatively tenacious and cohering bubbles filled with a non-inflammable gas. The chemicals composing the mixtures must moreover, be reasonably cheap; and the solutions should not deposit any appreciable amount of sediment, or otherwise materially deteriorate after standing for a considerable period. The chemical composition of each mixture must be so proportioned that a maximum amount of foam will be produced when equal volumes of the solution are brought together, 6 to 8 volumes of froth per unit volume of mixed solutions being considered efficient and good practice.

The formulae for standard "foamite" solutions have already been given in an earlier section.[2] A prominent refining company on the Pacific Coast [3] has used the following, claiming that the foam produced is composed of minute bubbles so tough and durable that a considerable quantity will remain for more than twenty-four hours after application.

[1] See p. 317.

[2] See p. 318.

[3] The Shell Company of California installed a foam-producing system in 1914 at its Coalinga plant, using foam-producing solutions (I).

*Foam-Producing Solutions (I)**

Solution A	Parts by weight	Solution B	Parts by weight
Water	100	Water	100
Aluminum sulphate (crystal)	10	Ground glue	1½
Sulphuric acid, 66° Bé	½	Glucose	½
		Sodium bicarbonate	7½
		Arsenious oxide	1/32

* U. S. Bureau of Mines, Bull. 170 (1918), 11 and 16.

Foam-Producing Solutions (II)

Solution A	Parts by weight	Solution B	Parts by weight
Water	100	Water	100
Aluminum sulphate (crystal)	12	Sodium bicarbonate	10
Acetic acid	½	Ground glue	1
Ground glue	1	Glucose	¼
Glucose	¼		

As already stated in the text concerning equipment, a high degree of permanency, with no bacterial decay is claimed for secondary licorice extract (foamite) solutions, which have displaced, to a great extent, formulae of the above type.

In regard to the amount of foaming solutions which must be stocked to furnish adequate protection, there is naturally some variation in opinion. For small installations it is generally advisable, however, to maintain about twice the quantity of foam-producing solutions that would be required to protect all tanks, this ratio decreasing with the increase in plant size, and being, of course, governed by the amount of crude storage, proximity of tanks to one another, nature of products manufactured, and general plant layout. For single units, computation may be based on the assumption of 6 gallons of foam produced per gallon of mixed solutions, at a rate of delivery sufficient to deposit a blanket of foam 5 inches thick in a five-minute period. On this basis the quantity of each solution required for various-sized tanks would be as follows:

	Gals. of each solution per minute
55,000-barrel tank (114 feet 6 inches diameter)	535
37,500-barrel tank (95 feet 6 inches diameter)	370
10,000-barrel tank (52 feet 0 inches diameter)	110
1,600-barrel tank (34 feet 0 inches diameter)	50

As it is obvious that the efficiency of all foam-producing mixtures depends on their ability to generate the maximum amount of lasting froth at all times, such solutions should be tested at regular intervals; those containing glue or glucose should be tested weekly, and those of a more permanent character, at least monthly. If depletion in strength is noted, it should be rectified immediately. Care should be taken in cold weather that solutions do not freeze; on the other hand, excessive heat should be avoided, as it will cause the sodium bicarbonate solution to lose much of its carbonic acid content, forming the normal carbonate to a considerable extent and greatly lowering the general efficiency of the system. In fact, where the solution has become weakened by the formation of an excess of normal carbonate, it is better to discard it entirely and start with fresh chemicals, rather than to attempt to replenish it with additional bicarbonate. With housed tanks and otherwise properly designed equipment, such a condition will never occur; but it is well to remember this source of danger.

V. YIELDS AND COSTS

In the analysis of refinery operations, profit or loss is dependent on four chief factors:

(a) Cost of crude.
(b) Cost of operation.
(c) Value of sales.
(d) Value of inventory.

With reference to (a), this will obviously include, besides the crude, minor quantities of equivalents, such as wax distillate, rod wax, etc., also transportation and premium charges; the final delivered cost will be the base for subsequent computation.

The cost of operation (b) may be subdivided into direct operating cost, indirect operating cost, and maintenance. Under the first-named is usually included superintendence, plant labor, operating materials and supplies, chemicals, fuel (electricity and gas), and sundries, such as lubricating oil, packing and waste. Under indirect cost of operation are commonly included such items as property tax, depreciation, insurance, laboratory and engineering expense, rentals, and office overhead, except sales. Maintenance will include the upkeep for the various buildings, tanks, equipment, etc., also changes in construction [1] that are essentially renewals or substitutions.

While each plant has its own particular system of distribution of accounts, in general they follow the lines indicated, and are usually designated by number or letter. For example, (B.M.) may represent building maintenance, this account to be charged with all builders' supplies, hardware, lumber, etc., used in the upkeep of any building, exclusive of permanent betterments or improvements which would be classed as investment charges under, say, account (B.). In large plants such an account as (B.M.) would be subdivided into separate costs for each individual building, as boiler house, wax plant, receiving house, etc.; although maintenance labor is commonly not distributed further than the main accounts, such as buildings, tanks, equipment, etc.

Where the numerical system of designation is employed, account (117) may, for instance, represent direct operating labor, subdivided into (a) superintendent, (b) stillmen, (c) boiler firemen, (d) wax-plant men, etc. In similar manner all the activities of the plant are segregated, all materials and supplies being commonly charged first to the warehouse, and later distributed to the different departments on written orders of authorized foremen. These orders state where and for what purpose the material is to be used, and after being entered as withdrawals in the stock book, should be promptly checked with the proper account letter or number, for if they are at all illegible, corrections can be made only when the order is fresh in the mind of the foreman who authorized them. Where a system of separate orders for each individual piece of work is maintained, the footings of the properly checked slips may be entered direct into the ledger for each day's operation, thus saving considerable bookkeeping expense. However, no hard-and-fast rule for determining operative costs can be generally applied to all plants, local conditions and individual preference for detailed information or summarized data governing the system and the size of the clerical force employed.

Under value of sales (c) are included the gross receipts and revenues obtained from the disposition of products, less the sales costs, which ordinarily include the following items: tank car rentals, cleaning of cars, switching and demurrage, deductible outgoing freight; telephone, telegraph and postage, advertising, commissions, and traveling expenses, also salaries of sales department.

If large stocks of various products are carried, the value of inventory (d),[2] even if

[1] New construction must be entered in the proper separate accounts, it having no bearing in the derivation of profit and loss, until maintenance charges, depreciation or insurance is imposed.

[2] Unless otherwise specified reference to inventory signifies oil stocks, the fluctuation in values of the inventory of materials and supplies being included under cost of operation and rarely approaching in importance the monetary worth of the oil in storage.

stocks are carried at low market prices, will often be greater in monetary value than the totals of the three other accounts combined; hence the great importance of correct evaluation of this factor. That this is easier to accomplish in theory than in practice is shown by the three systems of analysis employed in arriving at inventory totals, namely:

1. Inventory based on actual cost.
2. Inventory based on current market.
3. Inventory based on low market.

While at first thought, the carrying of inventory values at actual cost would seem to be the only correct method of arriving at true profit and loss, the results obtained are often misleading to the sales and executive branches, although, if correctly interpreted, they are of decided value. Further, while the derivation of true costs is simplicity itself in theory, in actual plant operation it is difficult and often costly in labor to keep separate the data necessary for the accounting department. The computations involved become tedious and more difficult with the successive refining steps, and usually finally result in values apparently bearing so little relation to the market that the real significance of the figures obtained is obscured.

Consider, for example, the derivation of the cost of production of the initial distillation products from a batch run of 38° Bé. Cushing crude to fuel oil. This is selected for simplicity in calculation, although involving the steps employed in more intricate computations. Assume that the cost of crude delivered to the plant, including refinery overhead, maintenance, etc., is $1.65 per barrel, and the fuel market 65 cents per barrel, and that the operating department has furnished the following data:

Operating Averages, Stripping 38° Bé. Cushing Crude to Fuel Oil

(Batch run, 1000 barrels)

Product	Yield, per cent	Fuel consumed	Period	Interval
Benzine...........	32.0	5.5 bbls.	Fired-over..........	4 hours
Kerosene distillate..	20.0	15.5 bbls.	Benzine cut.........	10 hours
Gas-oil............	7.0	17.0 bbls.	Distillate cut........	5 hours
Fuel oil...........	39.0	4.5 bbls.	Gas-oil cut..........	5 hours
Refining loss.......	2.0			
	100.0			

The increased cost of crude up to the point at which distillation begins is, therefore:

$$\text{Appreciated crude value, due to refining loss} = \frac{\$1.65}{98 \text{ per cent}} \qquad = \$1.683$$

Appreciated crude value, due to fuel consumed in raising to

$$\text{boiling point} = \$1.683 + \frac{5.5 \times \$0.50}{1000} \qquad = \$1.68575$$

Appreciated value due to stillman labor [1] expended in raising to

$$\text{boiling point} = \$1.68575 + \frac{3 \times \$6.00 \times 4}{1000 \times 24 \times 8} \qquad = \$1.68613$$

[1] The labor charge is computed on the basis of three stillmen at $6.00 per eight-hour shift, per twenty-four hour period, looking after eight stills.

The cost of the benzine will then be:

Appreciated value due to fuel consumed in distillation [1]

$$= \$1.68613 + \frac{40 \text{ per cent} \times 15.5 \times \$0.50}{320} = \$1.69582$$

Appreciated value due to stillman labor expended in distil-

$$\text{lation} = \$1.69582 + \frac{3 \times \$6.00 \times 10}{320 \times 24 \times 8} = \$1.69875$$

By similar computations the cost of the kerosene distillate, gas-oil and fuel oil [2] may be determined, the values of all products being summarized as follows:

Benzine	$1.69875 per bbl.
Kerosene distillate	1.71747 per bbl.
Gas-oil	1.75033 per bbl.
Fuel oil	1.69645 per bbl.

Since the above costs vary but slightly from one another, it is customary to omit the tedious calculations above, and give equal values to all the products of one distillation, thus:

$$\text{Appreciated value of all products, due to refining loss} = \frac{\$1.65}{98 \text{ per cent}} = \$1.683$$

Appreciated value of all products, due to fuel consumed in distillation

$$= \$1.683 + \frac{42.5 \text{ (total fuel)} \times \$0.50}{1000} = \$1.70425$$

Appreciated value of all products, due to labor expended in distillation

$$= \$1.70425 + \frac{3 \times \$6.00}{1000 \times 8} = \$1.70650$$

That is, the cost of the benzine, kerosene distillate, gas-oil, and fuel-oil is now $1.7065 per barrel. In similar manner the cost of all gasoline products and steam-still bottoms would be equal, and would be greater than the cost of the crude benzine by the amount of fuel, steam, acid, and labor expended. It will be noted, however, that one additional refinement finishes the bulk of the gasoline produced, whereas a product like non-viscous neutral must be taken through many steps, with the final result that its cost greatly exceeds that of gasoline, although it ordinarily sells far below the former commodity. Thus, while a true cost inventory will confuse, rather than aid, in some instances, in others its careful study will stimulate increased sales activity. Such a study may call the operating department's attention to the fact that less money would be lost, for instance, in allowing the non-viscous lubricating stocks to remain in gas-oil, than in finishing them to filtered neutral oils.

Another objection to true inventory values is the fact that, notwithstanding what the products cost, their real value is the present market; hence many refineries base

[1] The exact computation of fuel chargeable to the benzine distilled is a somewhat involved physico-chemical problem, but may be solved approximately thus:

32×125 (latent heat) $= 4000$ B.t.u.

67×0.45 (specific heat) $\times 200$ $(425° \text{ F.} - 225° \text{ F.}) = 6030$ B.t.u.

$\frac{4000}{4000 + 6030} = 40$ per cent of fuel oil consumed chargeable to benzine produced.

[2] In the above example, after proper deductions were made for fuel consumed in vaporization, it was found that 8.05 barrels were properly chargeable in raising the temperature of the residuum remaining in the still after the distillation of the gas-oil fraction.

their profit and loss statement on market quotations. When these are decidedly erratic, only a portion of the change in price is applied to each month's business. When a considerable bulk of stocks, produced at different periods, is in storage, a truer statement of conditions is obtained in this way than if extremely sudden market changes were applied.

The safest and most conservative plan is to adopt the low market system, in which all products are inventoried at the average of the lowest observed quotations during a chosen interval, say, two months. This course is probably followed by the majority of refiners. A few plants have instituted all three systems, invariably with increased efficiency in all departments. All cost systems, however, will fail to accomplish their true purpose unless the operating and sales departments have full knowledge of the results obtained by the accounting division. Too often these results are a matter of mysterious record, instead of being available where most needed. In not a few organizations there is a zeal for selling certain commodities, only equaled by the desire of the manufacturing department to produce them. In others, the sales department claims that the market for a certain product is so low that there is no profit in its sale; while in still others, the refinery, being stocked heavily with some intermediate, urges a sacrifice movement. In the first situation discussed above, a greater amount of cooperation between departments, together with actual cost comparisons, would often result in a reduction in the number of products made or sold. In the second case, the sales department would discover that a profit could be made on certain commodities even if sold at low market; and in the last case cited, the plant superintendent would learn of the great loss incurred in moving the intermediate in question, and would try to dispose of it through other channels. Several plants employ a system of graphs and curves, plotted on standard engineering or logarithmically ruled paper to bring out more clearly the fluctuations in costs, sales, yields, etc. These graphs are of value in proportion to promptness of issue; graphs drawn in May for February's business are of statistical worth only. In short, a cost system, whose results are understandable and available to the sales and operating branches, makes for high efficiency; while any other type becomes purely a machine for statistical information, with the really salient features buried in detail.

In discussing the subject of yield, a few comments on the monthly system of balance may not be out of place. While a balance covering a thirty-day period is practically necessary, if intelligible data on the yield of individual products are to be obtained, such a balance gives little opportunity for checking daily losses. As the detection of such losses is exceedingly difficult, even a day after their occurrence, the inadequacy of a monthly balance is apparent. Practically all plants take a daily inventory, but few strike a yield. Where yield is determined, it is only on tankage movements, the rest of the stocks being carried as unbalanced items " in process." With a little extra labor, i.e., by simultaneously gaging still contents and run-down tanks, and applying temperature corrections to the former and to other excessively hot stocks (such as flux, steam-refined stock, and melted paraffin wax) an accurate daily balance on total oil refined can be struck, with very little more clerical effort than is required to compute the inventory. Such practice enables losses to be quickly run down, is of decided value in case of fire, as an insurance record; and lastly, has a certain psychological effect in promoting higher operating efficiency, in that the employees know that each operation is being checked. Similarly, tank transfers, and treating and filtering losses should be carefully determined, and the information compiled should be daily available to the plant superintendent. Again, it must be remembered that reports over a day old are of no value, as it is practically impossible to detect carelessness or error in pumpings, transfers, etc., after a longer interval and it is inadvisable to discipline an employee for occurrences of which he has no recollection. While it is desirable that temperature

corrections be applied monthly to all tankage, such detail is not necessary in a daily balance; but thiefing of all tanks should be made daily, and the practice of gaging only the active stocks should be discouraged. Leaks develop, and transfers are made in error, in the best-regulated plants, and only the gaging of all tanks will disclose such faults. As an extra safeguard in operation, meters should be installed on all continuous processes, and results checked against tank transfers, simultaneous gaging being practiced only where absolutely necessary. Most refineries adopt 7 a.m. as the official time for the morning gage, and where an afternoon gage is taken, 4 p.m., is the usual hour. Stocks gaged in process should be credited to product charged; for example, the contents of a still on crude would be classed as such, even though nearly ready to pump out, the bottoms becoming fuel oil, flux or steam-refined stock (as the case may be) only after transfer to their respective tanks.

As a typical form for determining a daily balance the following one is suggested, although any other arrangement serving the same purpose would answer equally well.

Daily Refining Statement

	Barrels	Barrels
Inventory 7:00 a.m. yesterday	....	55,343.72
Crude received:		
Pipe line	4,521.23	
Tank cars	180.32	
	4,701.55	4,701.55
		60,045.27
Deduct:		
Yesterday's sales	3,691.78	
Fuel used	542.12	
Inventory 7:00 a.m. to-day	55,707.06	
Total	59,940.96	59,940.96
Loss–gain		104.31

Daily Crude Statement

	Barrels
Crude inventory 7:00 a.m. yesterday	35,910.18
Crude received	4,701.55
Total	40,611.73
Deduct:	
Crude inventory 7:00 a.m. to-day	35,708.09
Crude refined	4,903.64
Loss–gain	2.16 per cent

The following monthly yield statement, representing actual operating quantities obtained in refining 37° Bé. Oklahoma crude, is the form employed by a prominent Mid-Continent plant.

Crude Used in Refining

	Barrels	
Crude inventory 7:00 a.m. Feb. 1st..........	26,775.76	
Crude received..........................	155,531.48	
Total..........................	182,307.24	
Deduct:		
Crude inventory 7:00 a.m. March 1st......	34,149.08	
Crude refined..........................	148,158.16	
Oil refined..........................	143,011.79	
Refining loss..........................	5,146.37	3.5 per cent

The yearly yield and cost statements are, however, the really important deciding factors in refinery operation, since the high profits of one period may be entirely absorbed in the next quarter; or the average yield of the winter months considerably reduced by the adverse operating conditions of the hot season. In short, successful refinery operation is no longer the hit-or-miss proposition of a few years ago, but a manufacturing business in which the same attention must be given to details as in the manufacture of automobiles, or other like industry. With increasing competition and standardization of products, the question of profit is becoming more and more an operating burden. The coming decade will probably witness the reduction of refining losses to a negligible minimum, the introduction of economies in fuel consumption, and the application of chemical processes hitherto considered as visions of the theorist.

Monthly Statement of Shipments, Product Refined and Crude Used

....................Refinery 42 gallon barrels

February, 19..

Product	Inventory, Feb. 1st	Inventory, March 1st	Storage, increase	Storage, decrease	Shipped	Refined	Per cent	Per cent
Gas Av'n...........	690.00	711.84	21.84	.....	3,767.35	3,789.17	2.6	
Gas. Navy.........	420.93	2,161.14	1,740.21	.....	26,051.83	27,792.04	18.8	
Gas. 58 60.........	936.76	960.00	23.24	.....	10,627.62	10,650.86	7.1	
Naphtha 54 56......	3,345.53	13,629.54	10,284.01	.....	2,405.66	12,689.67	8.6	
Benzine...........	16,963.04	9,604.56	.....	7,358.48	.....	7,358.48	4.9*	32.2
44° Bé. W. W.......	4,487.26	0.00	.....	4,487.26	481.02	4,006.24	2.7*	
42° Bé. W. W.......	12,592.06	10,400.98	.....	2,191.08	30,426.31	28,235.23	19.0	
40° Bé. P. W.......	3,833.68	5,037.89	1,204.21	.....	5,903.07	7,107.28	4.5	21.2
Reruns.............	4,719.60	1,922.40	.....	2,797.20	.....	2,797.20	1.9*	
Gas-oil.............	2,980.15	3,567.05	586.90	.....	13,654.76	14,241.66	9.6	7.7
Road oil...........	21,117.21	40,959.38	19,842.17	.....	.....	19,842.17	13.4	
Fuel (used).........	.....	.....	.....	.....	15,283.21	.....		
Fuel oil...........	107,133.02	46,257.08	.....	60,875.94	72,746.[illegible]	27,153.93	18.3	31.7
Wax distillate.......	10,605.15	8,435.14	.....	2,170.01	.....	*2,170.01		
Wax oil...........	20,040.50	16,031.62	.....	4,008.88	......	*4,008.88		
Pres. distillate......	11,139.01	10,704.98	.....	434.03	.....	*434.03	4.5*	4.5*
Slack wax..........	1,396.31	1,207.14	.....	189.17	.....	*189.17		
Scale wax..........	744.93	798.13	53.20	.....	.....	53.20		
Finish. wax........	141.24	61.23	419.99	.....	841.17	1,261.16		
Foots oil...........	1,091.52	1,041.24	.....	50.28	.....	*50.28	0.7	0.7
Neutrals...........	5,207.29	613.46	.....	4.593.83	15,803.54	11,209.71	7.5	7.5
	229,585.19	174,104.80	19,470.82	74,951.21	198,492.18	143,011.79	96.5	96.5

* Quantities and percentages marked * represent minus values and are to be deducted in adding totals.

CRACKING PROCESSES

BY

ROLAND B. DAY

Introductory.—This subject is at present in an early stage of its development, an enormous mass of experimental work by many investigators having evolved only a few commercially complete processes. Dozens of other processes are gradually moving forward out of the embryonic stage toward practical operation. It is logical, therefore, to offer guides for experimental research as well as to show what has already been accomplished. It will be advisable likewise to refer the reader to publications on the subject which may prove helpful to him as they have to the author of this chapter. Such publications include Dr. Walter F. Rittman's "Manufacture of Benzene and Toluene from Petroleum and Other Hydrocarbons," Bureau of Mines

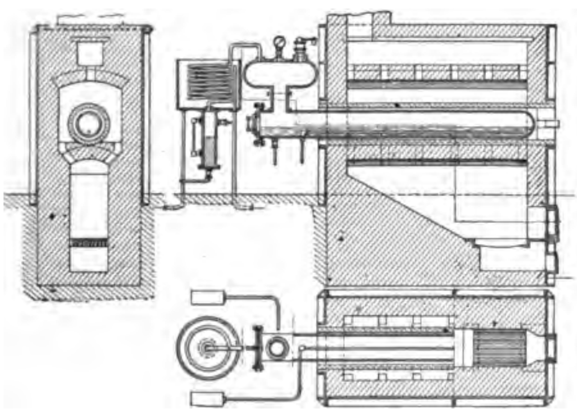


FIG. 1.—J. Dewar and B. Redwood's apparatus for the distillation of mineral oils and like products.

Bulletin 114; Sir Boverton Redwood's "A Treatise on Petroleum," and Bacon and Hamor's "The American Petroleum Industry."

The cracking process originated in 1861. The discovery was purely accidental, and was due to the failure of a stillman in Newark, N. J., to return to his still for a period of four hours when he should have returned in one. When he did return he found that the heavy residue which the still contained was producing a light distillate. Under ordinary circumstances the residue would have been removed after the products of the run had been distilled off, but in this instance the residue had been allowed to remain until a sufficient temperature had been reached to cause its dissociation into light distillates.

No practical application of cracking was introduced until four years after its discovery. During this interval various experiments were made, with the result that in 1865 patents were issued to Young and Benton. Young's process was conducted in the liquid phase in a still designed to effect condensation on the upper portions with the consequent dropping back of the condensed particles into the boiling liquid, thus causing dissociation.

Young proposed the use of pressure of from 10 to 20 pounds per square inch and aimed at the production of lamp oils and kerosene from Scottish shale oils.

The process of Benton followed that of Young, and was also conducted in the liquid phase. It was the first attempt to utilize tubes for cracking purposes. Benton

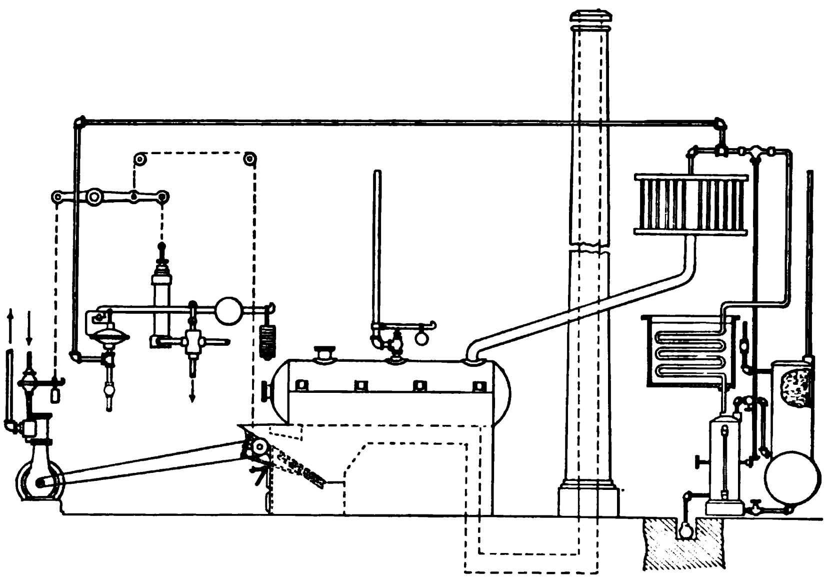


FIG. 2.—The Humphrey and Burton process. It produces more motor spirit than any thus far developed.

provided for a temperature ranging from 357° to 538° C. under a pressure of 500 pounds per square inch or less.

Others of the more important early patents were those issued to A. Reibeck's Mining Works and to J. Dewar and B. Redwood about 1890.

The last-named patent cove ed a process conducted in a still under pressure and designed for the production of lamp oils or kerosene. The experiments were made in Russia. Due to the production of comparatively large quantities of gasoline, which was practically unsalable at that time, the process was abandoned. This process resembled very closely the well-known Burton process, 'he principal diff rence being the emphasis that Burton placed upon condensation under pressure. Great credit is due to Dewar and Redwood for having produced so efficient an apparatus at such an early date.

Trend of Invention from Liquid Phase to Vapor Phase and Back to Liquid Phase

It will be seen from the foregoing discussion of the early application of cracking to the oil industry that the apparatus was designed to operate exclusively in the liquid phase. It was not until 1906 or 1908 that vapor-phase processes were introduced.

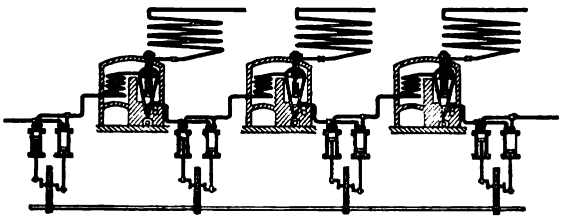


Fig. 3.—Price and Diets continuous vapor-phase process.

The earlier application of the liquid phase was probably due to the fact that all previous treatment of oil, such as distillation, had been carried on in the liquid phase, and it was, therefore, natural that this new process should follow these methods.

Upon the advent of the vapor-phase idea many investigators turned from the liquid phase and devoted all their efforts to designing processes which were operated in tubes

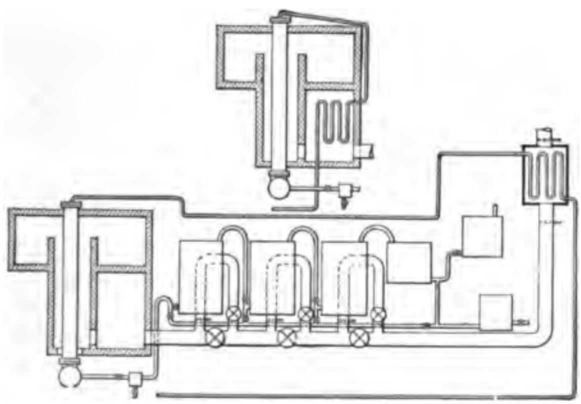


Fig. 4.—Rittman and Dutton, typical vapor-phase process.

in the vapor phase and under high pressure. These processes had certain features which apparently lent themselves to the production of gasoline and aromatic hydrocarbons. Much time and money have been spent in the development of this type.

A return to the liquid-phase idea is shown by the recent patents issued for cracking processes. The causes of this change may be apparent in the comparison of the liquid phase and vapor phase which is taken up in a later section of this chapter.

Comparison of Cracked Products and Natural Products

There is considerable prejudice in the minds of many refiners and of the public in general against cracked gasoline, but this prejudice is not justified in view of the results obtained. The percentage of unsaturated hydrocarbons contained in cracked gasoline, as a rule, is higher than in gasoline derived from straight distillation. The cracked product often contains as high as 20 to 25 per cent of unsaturated hydrocarbons. The question of the undesirable qualities of such hydrocarbons is debatable, there being no objectionable features about them except color and odor, difficulties that are readily eliminated by the use of ordinary refining methods and should not be considered a feature of great importance in the production of cracked gasoline on a commercial scale. The claim has often been made that crude cracked gasoline contains substances which polymerize into gummy substances objectionable in a carburetter. There is probably some basis for this claim, but these substances are easily removed by sulphuric acid. It is claimed further that even after treatment the yellowish color returns when the gasoline is allowed to stand in storage. This is not so if the treatment with sulphuric acid has been thorough. The time element in the treatment of gasoline has as much to do with the resultant product as the percentage of acid used. It is possible to clear up the average cracked gasoline entirely with 1 or 2 per cent of sulphuric acid if sufficient time is given. Redistillation with steam, as with many of the natural gasolines, is necessary. As a motor fuel cracked gasoline is considered by many writers on the subject to be superior to the natural product, in that it burns longer and delivers power during the entire stroke of the piston, whereas natural gasoline explodes more quickly. Moreover, a smaller quantity of cracked gasoline is required for the same mileage.

The specific gravity of the synthetic product is unquestionably always below that of distilled gasoline, partly for the reason that a significant percentage of benzol and other aromatics is present. In California, cracked gasoline with a specific gravity as low as 50° Bé. is being sold in the open market, and is preferred by some users.

Discussion of Commercial Problems Encountered in Cracking

Kerosene was the principal base oil used when the vapor-phase process was commercially introduced. It was expected, and rightly so, that this fraction from crude petroleum would yield a greater percentage of gasoline than would the heavier fractions. Besides, it gave little trouble through carbon formation. This use of kerosene arose after kerosene lamps had been partially eliminated by the substitution of gas and electricity and the price of kerosene had been forced to a point low enough to make profitable its cracking into gasoline. More recently, however, the market for kerosene in foreign lands, such as China, India, South America, Africa and other parts of the world where electricity and gas are not available, has brought the price to a point which prohibits its use as a base oil in cracking. There may still be a few isolated instances where this operation pays, but in the majority of cases kerosene may be eliminated as a possible base oil for cracking.

Light distillates of the cut from 35° to 40° Bé. are at present used to a large extent in cracking, but this class of oil is rapidly being incorporated into kerosene, with the possible exception of the distillates slightly above 35° Bé., say from 35° to 36° or 37°. It is, therefore, not an oil that can be relied upon to any great extent nor for any great length of time as material for cracking.

Heavy distillates, ranging from 25° to 35° Bé. are now the main base oil for

all branches of cracking. It is from a distillate of 30° to 35° that the Burton process produces roughly about 10 per cent of the gasoline supplied to this country. There is, however, a rising market for this heavy oil aside from its use as a base oil for cracking. The advent of the Diesel engine and its wide application to marine and stationary uses is now absorbing a large quantity of this distillate, and in the years to come the demand for this product will increase very rapidly. The price at the present time is low enough to justify its use as a base oil for the production of synthetic gasoline, but how long this condition will remain is a question. The Diesel oil engine can afford, on the basis of efficiency as compared with fuel oil burners, to pay a price which would eliminate all possibility of profit from cracking operations on this oil. This heavy distillate, or gas-oil, which is the term often applied to it, is also in great demand by the manufacturers of illuminating gas. In the production of illuminating gas from the distillation of coal it is used to bring up the illuminating value of gas, and is therefore very essential to that industry, as the increased candle-power is vitally necessary, and heavier distillates are difficult to use, on account of the excessive amounts of lamp black and carbon formed. It is, therefore, probable that eventually this grade of distillate will also be eliminated from the field of possible oils for cracking purposes.

Only heavy crude oils which contain little or no gasoline, and refinery residue, (now classified as fuel oils) remain to the cracking engineer, should the forecast in the previous subheadings in this section become true. The cracking of these oils offers greater profit than that of any other oil. It has, to be sure, many difficulties in the way of carbon formation, decreased yield and formation of large amounts of permanent gas. The price, however, more than offsets these disadvantages, and recent experiments have shown that it is possible to produce a profitable amount of gasoline from such oils as Panuco crude and refinery residues, when the Baumé gravity is as low as 10°. From such an oil the author recently witnessed the production of 25 per cent of gasoline 30 per cent of distillate of 31° Bé. and 20 per cent heavy asphalt, containing some free carbon. Obviously if this result is derived economically it offers a remarkable profit, since Panuco crude can be bought at the wells for from 20 to 40 cents a barrel. Such oils as those produced in the Panuco field are not at the present time salable even as fuel oil, due to the large percentage of sulphur and water present in them. These difficulties are all obviated when the oil is cracked; the water passing out with the cracked distillate is readily separated; most of the sulphur becomes sulphureted hydrogen and passes off with the gas. The heavy asphalt which is produced in the process may be utilized as a fuel if burned while still hot, but has little value as commercial asphalt, due to the presence of from 3 to 4 per cent of free carbon.

Some Mechanical Problems and Possible Solution

Means of removing carbon.—The most persistent difficulty encountered in the cracking of any oil is the formation of such amounts of fixed carbon as will eventually choke the apparatus, or, in the case of stills, will form a heat-insulating area on the bottom which causes overheating of the metal shell. This one problem has done more to retard the advance of the cracking industry than has any other one thing, and its solution has been attempted in many ways. In the first cracking still, the carbon was left deposited on the bottom of the still till the run was completed. It was then necessary to enter the still and remove this carbon with picks. This entailed considerable expense and the necessity of cooling the still to a temperature at which a man could enter. Various means of removal or prevention have been proposed, some of them mechanical, and some involving the use of water for the prevention of excessive for-

mation of carbon. The mechanical apparatus consisted in most cases of scrapers or stirring-rods which kept the carbon from adhering to the metal walls of the tube or still. These were only partially successful in most instances. It is obvious that a great deal of mechanism would be required to cover the entire area of the bottom of a pressure still used in the liquid-phase process; while in the vapor-phase process an equally grave difficulty would be encountered were stirring-rods or scrapers to be used in the tubes, because the passing of radiant heat from the tubes to the scrapers would raise the temperature of the scrapers to a point where carbon would adhere to them. The device of employing stirring-rods in tubes has been used with only partial success, for while they kept the walls of the tube clean, they themselves collected carbon which eventually built from them to the walls of the tubes. In the design of any cracking plant means should be provided whereby the carbon is prevented from forming in any large amount, or else some mechanical device should be installed for the removal of it.

All metal parts of any cracking apparatus which are directly exposed to the heat of the furnace should either be composed of some special alloy built to withstand high temperature, oxidation and crystallization or should be treated by some nickeling process which would prevent decomposition from the above causes. Such metals are obtainable at reasonable cost, and unless they are provided, rapid oxidation from combustion takes place on the outside of the metal, and crystallization, due to a chemical bond formed between the carbon and the metal, will result. This crystallization has the disadvantage of making the metal very brittle and reducing its efficiency as a heat conductor.

Efficient furnace designs.—The design of a cracking furnace is obviously a matter which cannot be specified in a book of this character, due to the wide difference in type of apparatus used. Great care should be taken, however, in furnace design and the best possible use made of all the heat generated. The efficiency of the furnace can be checked by taking readings of the temperature of the gases of combustion by placing pyrometers at the base of the stack. If this temperature is above normal the furnace design is faulty in some respect. One of the most expensive items in the cracking of oil is the production of the necessary heat, and too much stress cannot be laid upon complete heat utilization.

Preheaters.—A more efficient utilization of heat may be obtained by the use of preheaters, which may be located either in the waste gases of combustion after they have passed to the stack or in the condensing apparatus for the cracked product. Care, however, should be exercised that these preheaters, which in most cases are coils, do not become overheated, as carbon will then be formed in the pipes, making it necessary to clean them.

Fractional condensation.—Much work has recently been done in an attempt to obviate the necessity of redistillation of cracked products by fractionally condensing them. There are now standard condensers on the market which consist of a vertical cylinder in which a series of small tubes are inserted. Water enters at the bottom around these small tubes and is drawn off at the top. The oil vapors entering the tubes at the top are drawn from the bottom. One or more of these condensers may be used, according to the number of fractions or cuts that are desired, the temperature being progressively lower in each condenser. In many cases it is desirable to make only two fractions, gasoline and everything heavier than gasoline.

Utilization of so-called waste products.—There are two main sources of waste in connection with the cracking of oil. The first is permanent gas and the second is carbon and tar. The gas problem is best attacked in the preventive stage, and, while the production of gas will vary with different oils, this loss should not amount to more than 10 per cent, even with very heavy crudes. As it furnishes an additional fuel

and is generally used as such, it is not an actual loss. The tars and carbon produced in cracking, if they can be drawn from the apparatus in a liquid state, should also be burned, preferably while still retaining a large portion of the heat absorbed in the apparatus.

Types of feed-pump control.—The average steam-pump is not applicable to any form of tube process in either the vapor or the liquid phase. It is impossible to control accurately the input of such pumps, and variations in boiler pressures will constantly change the rate of feed. Much trouble may arise from this source, and wherever possible, pumps geared to electric variable-speed motors should be used. If electricity is not available, some form of steam-pump diaphragm which will prevent variation in speed caused by variation in steam pressure, should be employed.

Oil and water feed.—In a number of vapor-phase processes water and oil are fed in predetermined proportion into the cracking apparatus. The advantage to be derived in most cases depends upon very accurate control of these proportions, too much water resulting in loss of thermal efficiency and too little resulting in failure to prevent formation of carbon. A type of pump which has been developed for this service has

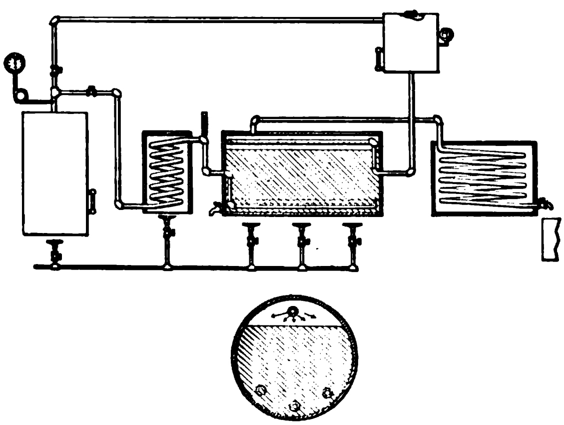


FIG. 5.—Kormann process, using super-heated steam.

three cylinders and is geared to a variable-speed motor. Two of the cylinders are used for oil while the third has a variable-stroke piston, so that the proportion of water to oil may be varied from nothing to 33⅓ per cent by lengthening or shortening the stroke of this piston. Some of the processes call for vaporization previous to the injection into the cracking tube, which is an excellent provision as the oil and water when vaporized separately form a much more perfect mixture than when allowed to enter in the liquid state through a common pipe. In the latter case the oil and water are apt to enter alternately.

Electricity as a source of heat.—Several patentees have recently proposed to use electrical energy as a source of heat, for the obvious reason that the heat from this source can be controlled more easily. Several experiments have been conducted to determine the advisability of using this form of heat. There are doubtless many advantages, but the cost of operation, in some localities at least, would be prohibitive. The writer is awaiting with much interest the results of some tests on a commercial scale now being conducted. It is to be hoped that they will prove successful and that additional yield of gasoline due to more accurate heat control will help to pay the additional cost.

Some Chemical Problems and Possible Solutions

The cause of carbon formation is local overheating of the hydrocarbons under treatment. A molecule remains too long in contact with the heated wall of the vessel, and thus rapidly absorbs heat, which it is not able to pass on to the surrounding molecules fast enough to maintain a uniform temperature. The result is the complete decomposition of the overheated molecule into permanent gas and carbon, the gas readily passing out of the apparatus and the carbon adhering to the walls of the cracking chamber.

Time, therefore, is one of the principal elements to be considered in the elimination of carbon. The word "time," in this instance, is not used to indicate the total time during which the oil remains in the cracking zone, but the time that a given molecule is in contact with the hot metal. If, therefore, it is possible in a proposed apparatus to control by any means the time of contact between the molecule and the hot metal, and if, in addition, the temperature of the apparatus is raised progressively so that the oil enters cold or slightly preheated and gradually becomes heated to the highest desired temperature, there will be a point during the flow of the oil through the apparatus where the temperature and the time of contact are right for the partial dissociation of the molecule, resulting in the desired product. This element of time may remain

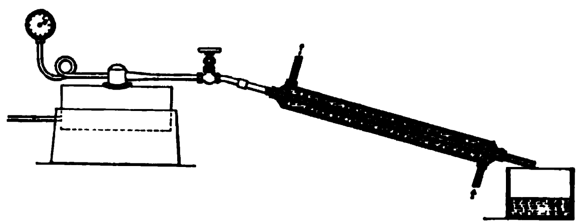


Fig. 6.—Bacon and Clark, a typical pressure-still apparatus.

fixed or constant, for the problem is to get just enough heat into the molecule to bring about the reaction to a limited degree. Therefore, if a given molecule touches the hot surface once in every foot of travel in the cracking chamber and the temperature of the chamber is progressively higher at each contact a close approximation of the ideal condition for the minimum of carbon formation and the maximum amount of salable product will eventually result. It must be remembered at all times, in dealing with any cracking problem, that oil is not a uniform substance such as water, with a uniform boiling point and a uniform chemical composition, but that it is a complex combination of substances of different boiling points which will react differently under the same conditions.

In general it may be stated that the higher the boiling range of a given oil the lower the temperature at which it will decompose. For instance, heavy asphaltic oils or paraffin react at a much lower temperature than does kerosene. It is, therefore, necessary in treating any oil to provide variable conditions which will suit the various constituents composing the oil. These conditions can be determined only by experimental work on the oil in question; but in general it may be stated that no process can be ideal which submits a distillate or crude to the maximum temperature in the shortest possible time.

A number of processes call for the injection of water in definite proportions with oil, and some very interesting results have been claimed. The action, however, is not what the inventor in some cases has claimed, namely, the decomposition of the water

into its elements resulting in the hydrogenation of unsaturated hydrocarbons and the oxidation of carbon to form carbon monoxide and carbon dioxide. It is rather the action of a heat balancer in preventing local overheating (due to the relatively high specific heat of the water).

Pressure is a very necessary factor in the production of the maximum amount of desirable hydrocarbons from a given oil. Its action tends to reduce the amount of unsaturated hydrocarbons formed, and, in the liquid-phase processes, it raises the vaporizing point of the oil under treatment above the temperature necessary to crack it, thus preventing straight distillation. The advantage of condensation under higher pressure over condensation at atmospheric pressure is open to question.

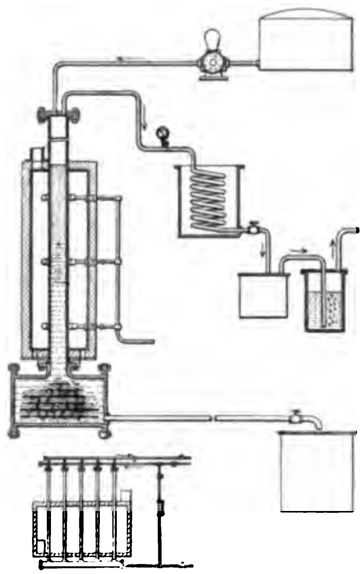


FIG. 7.—Bacon, Brooks and Clark cracking process.

In "The American Petroleum Industry," Bacon and Hamor set forth a series of experiments which would indicate that there is nothing to be gained by condensation under pressure; on the other hand, Dr. Burton, who is responsible for the well-known process used by the various Standard Oil Companies, claims that condensation under pressure decreases the percentage of unsaturated hydrocarbons produced. It is believed by the author that condensation under pressure has no effect upon the chemical composition of the resultant product.

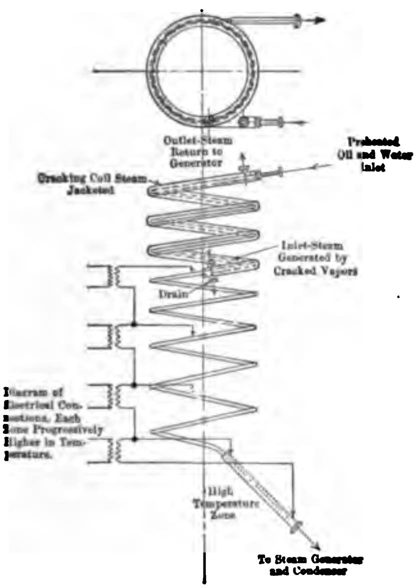


FIG. 8.—McComb vapor-phase process.

The effect of catalysts as a means of accelerating the cracking action of oil when subjected to heat is a much discussed subject, and a great variety of substances have been proposed which are supposed to have the desired result. The effect of many of these substances may be attributed to the fact that they offer additional hot surface upon which the molecules may react. Others, such as platinum and nickel, may exert some influence because of their affinity for hydrogen; iron and steel may have some influence because of their slight affinity for carbon.

The application of catalysts is often a difficult problem because they make obstructions in the cracking chamber, often causing stoppages. Other substances, such as anhydrous aluminum chloride and other metal chlorides and oxides, have been used and are being used, the great difficulty with such agents being the recovery of the catalyst. McAfee has secured two patents covering the recovery of aluminum chloride after the after distillation of a charge of oil in a still. It is

claimed that the product derived by the use of aluminum chloride is water-white and has no bad odor. Catalysts are not, however, by any means essential nor in most cases altogether desirable in a cracking process, since the most successful and best-known processes make no use of them whatever.

Comparison of Liquid- and Vapor-Phase Processes

The advantages of cracking in the liquid phase are many, and are often overlooked by the investigators working in the vapor phase. The thermal efficiency may

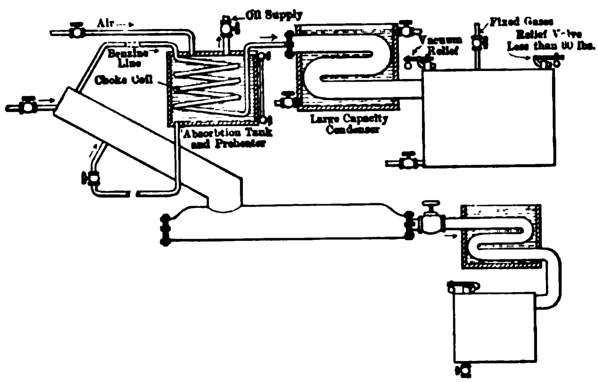


Fig. 9.—Wellman liquid-phase process.

be successfully compared with the generation of steam from cold water on one hand and the superheating of steam on the other. It is extremely expensive to heat a vapor through a metal. In the liquid phase the oil is heated progressively and at an even rate so that each molecule has an opportunity to react at a temperature best suited to it. This is an extremely important consideration. The tendency toward local overheating is less in the liquid phase than in the vapor phase because heat is more readily conducted through the liquid, resulting in more even heat distribution. Carbon does not adhere so readily to the walls of the cracking chamber, but is more apt to float off in the oil to be drawn off with the heavy residue or tar, especially if the oil is slightly agitated. The formation of an insulating shell is thus retarded. The control of pumps feeding oil into an apparatus operating in the liquid phase need not be so carefully watched as in the vapor phase, on account of the relatively large volume of oil involved. This large volume of oil handled in the liquid phase, as contrasted with the small volumes of the vapor phase, is in itself a great advantage as it prevents wide variation in temperature even when the feed is intermittent. Where tubes or pipes are used as cracking chambers in the liquid phase, practically all of the advantages of the vapor phase are present with few of its defects. In such an apparatus the feed may be continuous, the carbon may be removed continuously, water may be present without causing " bumping " (which occurs when water is present in a still), all grades of oil may be used with success and any desired pressure may be applied with little danger of fire. The tubes may be so arranged that heat is utilized to the best possible advantage. Stirring mechanism may be used without carbon forming thereon, due to the fact that the oil blocks the radiant heat and the stirring mechanism can therefore only attain a temperature equal to that of the oil. Carbon will adhere to metal only when the metal is at a higher temperature than the oil under treatment. In

the liquid phase it is possible to treat heavy non-volatile oils which decompose in some cases, at temperatures below their boiling points, and which are, therefore, not susceptible of vaporization prior to cracking treatment. These properties preclude the possibility of their being used in a vapor-phase process. Catalysts such as aluminum chloride or other metal chlorides or oxides may be readily used in the liquid phase while their application to the vapor phase would prove a difficult problem. Crude oils containing a refinable percentage of gasoline may be cracked in the liquid phase without previous treatment, thus saving the cost of distillation and securing a blend of the cracked gasoline with the natural product.

Advantages of the vapor-phase process.—The advantages of the vapor-phase processes are (1) the small amount of oil exposed to heat in the event of breakage resulting in a fire; (2) the possibility of varying pressure and temperature independently

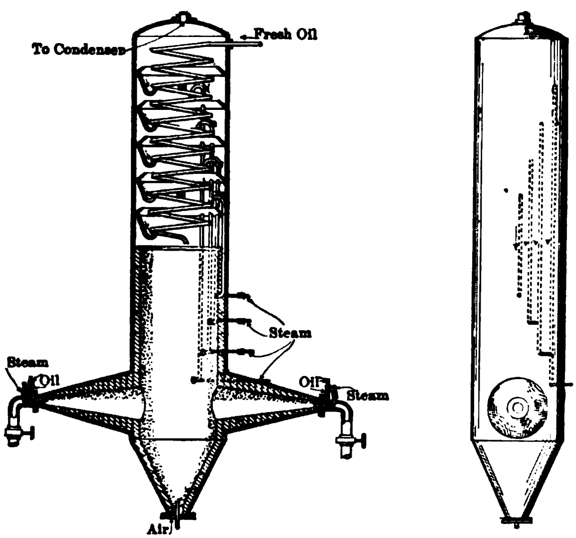


FIG. 10.—Illustrating a type of apparatus in which the conversion is effected by contact between hot gases of combustion devoid of oxygen and the oil vapor.

of each other, enabling the vapor-phase plant to crack successfully light distillates such as kerosene, which would vaporize in a liquid-phase plant and pass out unless a very high pressure was used; (3) the ready adaptability of such catalysts as platinum sponge and wire or other metals and alloys which exert a catalytic influence. For the production of aromatic hydrocarbons, such as benzene, toluene, xylene, anthracene and naphthalene, from petroleum, the vapor-phase process is without doubt the only commercial possibility. The work of Rittman and others prove that as much as 13 per cent may be obtained, these percentages being largely benzene and toluene. The commercia importance of this phase of cracking is at the present time questionable, owing to the limited demand for these products, and to the excessive wear and tear on the apparatus, due to high temperature and pressure. The disadvantages of the liquid phase may be summed up as follows: large amount of oil exposed in cases of fracture of any vital part of the apparatus (which, however, applies only to pressure stills); inability to apply such catalysts as platinum sponge, nickel, and various alloys which have catalytic action; inability to use very light distillates, such as kerosene, without extremely high pressure, which application is impossible to a still of average

strength. Unless some stirring mechanism is used carbon settles to the bottom of the still. Too high a temperature results in overheating of the shell and the burning out of some part.

Disadvantages of the vapor-phase process.—One disadvantage of a great majority of the processes operating in the vapor phase is the high temperature at which the cracking tube is usually maintained, in many cases 900° or above. If high pressure is used, the tubes are often enlarged or blown out; the metal, therefore, becomes thinner, and breaks are the ultimate result. This is often true even though calorized pipes or alloys, which are not readily oxidized, are used. Another difficulty results from the inability to use successfully any form of stirring or scraping mechanism because of the radiant heat which raises the temperature of such mechanism to the point where carbon will adhere to it; and while carbon may, by this method, be kept from the walls of the tube, it has not so far been kept from the stirring mechanism itself. The tube,

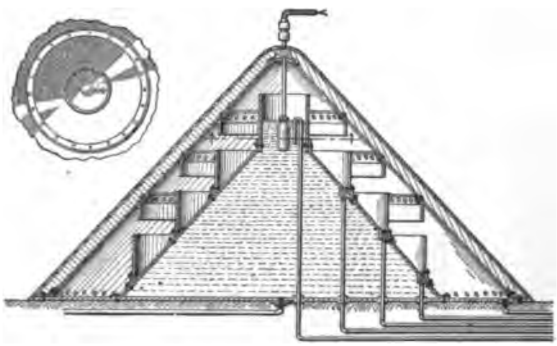


FIG. 11.—Evans cracking process.

therefore, is closed by carbon. The extremely high temperature at which these tubes are maintained causes extreme overheating of such molecules as come in actual contact with the metal, resulting in total decomposition to permanent gas and carbon. This decreases the yield of profitable products and increases the mechanical difficulties. The difficulties of heating a gas or vapor in a metal container are well known and require no comment other than the fact that it is an expensive operation. The difficulties of heating a very heavy oil which does not readily vaporize at a temperature below that at which it cracks are, first, that such oils when treated in vertical tubes will fall out of the cracking zone before being acted upon, and, second, that it is impossible to supply a means of vaporizing them without some accumulation of carbon, as many of them will crack prior to vaporization. If large tubes are used, channeling will occur, and much of the vapor will pass through without ever having attained the temperature necessary to effect conversion. If the attempt is made to overcome this difficulty by raising the temperature of the tube, the periphery of the tube becomes so hot that the molecules coming in contact with it are still further overheated. If no means are provided for the removal of carbon a coating is eventually formed on the walls of the tubes. This coating acts as a heat insulator and necessitates greater fuel consumption and higher temperature of the tube. Finally, it is impossible to apply such catalysts as anhydrous aluminum chloride or other metallic chlorides and oxides.

Cracking Research on a Commercial Basis

Expense.—The subject of research has been seriously taken up by the oil industry only within the past ten years, and only a limited number of companies have recognized its commercial value.

In a number of instances research has paid enormous dividends on the actual cash outlay and there are other instances, due either to faulty policy of the company, or

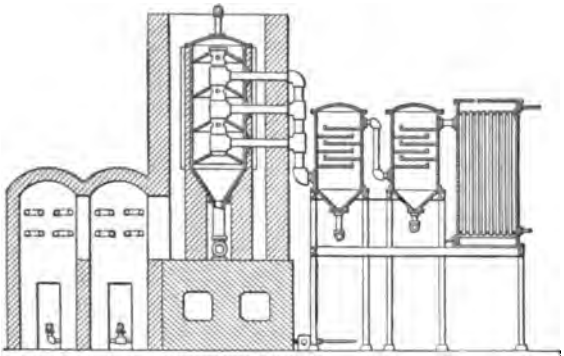


FIG. 12.—Trumble liquid-phase process.

inefficiency of the men conducting the work, where research has been a total failure from a commercial point of view. From a purely technical standpoint, however, it

FIG. 13.—McComb cracking plant, Havana, Cuba.

is a subject worthy of serious investigation by any company not already engaged in such work.

Instances such as that of the General Electric Company prove beyond question that considerable sums of money may be spent without danger of loss. Fully 50 per cent of the products at present produced by the General Electric Company are the direct results of research work in their own laboratories.

It is to be hoped that in the future the oil industry will devote more attention to the manufacture of products not heretofore derived from petroleum, and it is safe to say that all companies engaged in this work will be amply repaid.

Patents on the Production of Light Oils from Petroleum

The following patents for cracking petroleum oils are selected as representative of the various types previously referred to in this chapter:

Abel, C. D.: Treatment of hydrocarbons for their purification into other products. English patent, No. 4769, Dec. 15, 1877. Low-grade petroleum is treated with aluminum chloride, or a mixture of aluminum chloride and metallic oxides at 100° to 600° C.

Adams, J. H.: Oil-converting process. U. S. patent, No. 976,975, Nov. 29, 1910, Jour. Soc. Chem. Ind., vol. 30, Feb. 28, 1911, p. 202. Kerosene and similar oils are cracked by bringing them in contact with an incandescent electric heater. The oil is heated as far as possible by direct contact.

Bacon, R. F., Brooks, B. T. and Clark, C. W.: U. S. patent, No. 1,334,731, Mar. 23, 1920. A liquid-phase process using vertical tubes with a tar and carbon pot at the bottom. The tubes are from 6 to 19 inches in diameter and are kept filled with oil to the top of the furnace. (See illustration, Fig. 7.)

Benton, G. L.: U. S. patent, No. 342,564, May 26, 1886. Process of cracking petroleum in which the oil is heated to a temperature of 700° F. to 1000° F. under a pressure of 500 pounds per square inch and then expanded into a second chamber maintained at the same temperature.

Bergius, F.: Production of light hydrocarbons from heavy hydrocarbons, English patent, No. 4574, Feb. 21, 1914; French patent, No. 470,551, April 6, 1914. The heavy hydrocarbons are subjected to the action of hydrogen, nitrogen, carbon monoxide, or methane at a pressure of 100 atmospheres while heated to a temperature below 420° C.

Burke, C. R.: U. S. patent, No. 1,344,258, June 22, 1920. Oil is cracked in the liquid phase and the resultant cracked vapors are mingled with natural gas and compressed.

Burton, W. M.: U. S. patent, No. 1,049,667, Jan. 7, 1913. Process for the manufacture of gasoline from distillate with a boiling point of 500° F. at temperatures of 650° to 850° F. and pressures of 4 to 5 atmospheres. There are several patents connected with this process, but since one of them is the best-known process yet developed, only that one is given. This is the only process of cracking oil that has had any marked effect on the production of gasoline, and while some of the others might have done as well with the same backing, the fact remains that this process is the only successful large-scale commercial development of the art to date.

Clark, E. M.: U. S. patent, No. 1,119,496, Dec. 1, 1914. Method of circulating the liquid rapidly in small tubes under pressure of 3 to 7 atmospheres at a temperature of 650° to 850° F. Cracked vapors are taken off and condensed.

Coast, J. W.: U. S. patent, No. 1,349,794, Aug. 17, 1920. An apparatus comprising a proposed means of removing carbon from a still. (*Note.* Several patents have been issued to the above patentee for various means of removing carbon from pressure stills.)

Continental Caoutchouc and Gutta-Percha Co.: English patent, No. 7112, Mar. 20, 1914. The oil is passed over products obtained from aluminum halides and hydrocarbons or halogenalkyls as catalyzers. The catalyzers may be absorbed in a porous substance.

Cosden, J. S., and Coast, J. W.: U. S. patent, No. 1,258,196, Mar. 5, 1918. Oil is cracked under pressure in a still, and natural gas heated to a temperature of 900° F. is injected into the vapor line; this mixture is then carried to a second cracking chamber where the fresh oil, which is continuously injected in the form of a fine spray, is acted upon by the hot vapors. This second chamber serves the triple purpose of cracking some of the fresh oil, condensing some of the cracked vapors from the still and preheating fresh oil that will not crack at the temperature of this chamber. There are three such chambers, in addition to the still, which are maintained at progressively lower temperatures.

Cowper-Coles, S. O.: English patent, No. 27,945, 1908. Paraffin is heated in a still and the vapors are led through small metal tubes at a temperature of 1700° F. and condensed.

Danckwardt, P.: Process for the production of gasoline and naphtha from crude oil, petroleum products, coal tar or similar products. U. S. patent, No. 1,141,529, June 1, 1915. Heated liquid is sprayed into a retort, then withdrawn and passed through a heater, and back to the retort. A spray of molten lead alloy, or fused sodium nitrate or sodium hydroxide is passed into the retort.

Day, D. T.: The process of refining and purifying hydrocarbon oils. U. S. patent, No. 826,089, July 17, 1906. Hydrogen or absorbable hydrocarbon vapor is added under pressure, in the presence of a porous absorptive substance capable of absorbing hydrogen or a hydrogen-carrying gas or vapor. Such porous bodies as fuller's earth, zinc dust and iron oxides are preferred.

Day, R. B.: U. S. patent, No. 1,357,277, Nov. 2, 1920. Process providing for fractional distillation and treatment of different fractions at different temperatures. Heat is supplied by gases of combustion devoid of oxygen. The oil vapors are injected into such gases.

Dewar, James, and Redwood, Boverton: U. S. patent, No. 419,931, Jan. 21, 1890. Method of distilling mineral oils under pressure.

Dougherty, A. A.: U. S. patent, No. 1,353,638, Sept. 21, 1920. A liquid-phase process in which oil is injected in the form of a fine spray into a still, already charged and heated. Upon contact with the hot oil in the still the injected oil is converted.

Dubbs, J. A.: U. S. patent, No. 1,135,506, April 13, 1915. Petroleum is mixed with water and atomized under pressure into a heated chamber, where temperatures of 300° to 600° F. and pressures of 50 to 600 pounds are maintained.

Ellis, C.: English patent, No. 25,631, Nov. 8, 1912. The oils are injected into a chamber filled with fire-brick or other refractory material. Sufficient air is injected through other nozzles to serve for combustion of a small part of this oil, the remainder being vaporized and cracked under a pressure of 30 to 60 pounds. The refractory material is coated with a layer of catalytic material such as thorium, vanadium or precipitated alumina, attached by means of feldspar.

Emerson, V. L.: U. S. patent, No. 1,346,797, July, 13, 1920. A liquid-phase process conducted in a still.

Evans, J. G. P.: U. S. patent, No. 1,366,643, Jan. 25, 1921. A liquid-phase process in which the oil is heated from the top to overcome the boiling action which occurs when heat is applied to the bottom of a still.

Fenchelle, H. E., and Perkin, F. M.: English patent, No. 6547, Mar. 14, 1914. The heavy hydrocarbons are cracked by forcing them under pressure through one or

more long, narrow, heated conduits, the resulting liquid being cooled under pressure and allowed to escape at a lower pressure into a chamber surmounted by a rectifying column. Temperatures of 500° to 600° F., and pressures of 50 to 60 atmospheres are used.

Foreward, C. B.: U. S. patent, No. 1,299,449, April, 8, 1919. A vapor-phase process using superheated steam as the heating agent. The oil is heated progressively and the steam is injected at high temperature into the oil vapor.

Friedel, C., and Crafts, J. M.: English patent, No. 4769, 1887. Patent filed by C. D. Abel. The hydrocarbons are treated with aluminum or other metallic chlorides at temperatures of 100° to 600° C. Metallic oxides also may be used.

Gray, G. W.: English patent, No. 17,838, Aug. 5, 1913. Oil is heated in the presence of anhydrous aluminum or ferric chloride, to a temperature of 400° to 600° F.

Gray, J. L.: Canadian patent, No. 153,966, Feb. 9, 1914. The oil is passed through a bath of molten metal at a temperature sufficient to crack it.

Greenstreet, C. J.: U. S. patent, No. 1,110,923, Sept. 15, 1914. This process covers forcing crude oil through a long coil of pipe at cherry-red heat. The oil vapor is mixed with steam.

Hall, W. A.: English patent, No. 2,948, Feb. 4, 1914. Oil is passed through a coil at 600°, at such a rate that only about 25 per cent is converted into gas, and super-heating is avoided. The product after passing through alcohol, is condensed.

Hall, W. A.: English patent, No. 17,121, July 25, 1914. Hydrocarbon vapors are heated to above 600° C. in the presence of a suitable catalyzer, and under a pressure of 5 atmospheres. The resulting vapors are passed through an expansion chamber. Oxides of nickel, cobalt, silver, platinum, or chromium manganese may be used as catalyzers. Cracked vapors may be purified by passing through fuller's earth.

Hall, W. A.: U. S. patent, No. 1,285,136, Nov. 19, 1918. Oil vapor is passed through tubes at high velocity, with traps for removal of carbon. This process has gained considerable favor with many engineers both here and abroad.

Hirschberg, Leon: English patent, No. 4573, Feb. 21, 1914. Heavy hydrocarbons are converted into lighter hydrocarbons by contact in a finely divided state with a catalyzer such as chromium oxide, at dull-red heat. Pressure of 15 to 55 pounds per square inch.

Humphreys, R. E.: U. S. patent, No. 1,119,700. Oils boiling over 500° F. are distilled under pressure of over 4 atmospheres; heavier fractions are condensed and returned for further treatment.

Hyndman, H. M.: French patent, No. 462,484, Sept. 11, 1913. Oil is passed through a heated spiral pipe at a cherry-red heat and under pressure.

Kittle, H. A.: English patent, No. 8334, April 6, 1909. Oil is vaporized at a temperature above the boiling point of the highest-boiling constituent by passing through a bath of molten metal.

Korman, F. A.: U. S. patent, No. 1,332,849, Mar. 2, 1920. Cold oil is absorbed by a heated porous substance such as fire-brick. When the point of maximum absorption is reached, superheated steam is injected to reheat the brick and vaporize the oil; the resulting vapors are condensed.

Lamplough, F.: English patent, No. 28,101, Dec. 5, 1912. Oil with 10 per cent of water is passed through a series of U-tubes containing nickel rods at a dull-red heat. The resulting vapors are condensed.

Laing, J.: English patent, No. 11,757, July 28, 1890. Vapors from a still are passed through a superheater and further cracked, thus producing more light hydrocarbons than would otherwise be produced.

Lewis, J. W.: U. S. patent, No. 1,364,443, Jan. 4, 1921. A common type of liquid-phase process conducted in a still.

McAfee, A. M.: U. S. patent, No. 1,127,465. Oil is distilled in the presence of 1 to 5 per cent of aluminum chloride. Large yields of gasoline are obtained.

McComb, W. M.: U. S. patent, No. 1,337,144, April 13, 1920. A vapor-phase process using steam and a catalyzer of nickel or platinum. The oil and water or steam are passed through a spiral tube and heated progressively.

Moeller, J., and Woltereck, H. C.: English patent, No. 16,611, July 19, 1913. Vapors of oil and steam at a temperature of 700° C. are passed through a bed of coke heated to 700° C.

New Oil Refining Process, Ltd. and Nelson, R. G.: English patent, No. 13,726, June 13, 1913. Oil and water are decomposed by the action of scrap iron, iron carbide, copper, aluminum, bauxite, broken brick, coke or alumina at a temperature of 1000° to 1200° F.

Noad, J. and T. E.: English patent, No. 3607, Feb. 13, 1912. Oil and water are decomposed together in the presence of iron heated to a temperature of 900° F.

Planes, Ltd., and Thompson, W. P.: English patent, No. 21,273, Sept. 20, 1913. Oil is heated in a cracking still in the presence of finely divided nickel. Hydrogen or water gas may also be used to improve the product. A temperature of 300° C. and pressures of from 5 to 100 pounds per square inch are used.

Price, W. B., and Dietz, E.: U. S. patent, No. 1,349,294, Aug. 10, 1920. A process in which special mention is made of the length of time the oil is under treatment.

Renard, G.: English patent, No. 3413, Feb. 10, 1913. A liquid-phase process in which the oil is heated in coils of pipe to a temperature of 400° to 500° C., under a pressure of 40 to 50 atmospheres.

Rittman W., and Dutton, C. B.: U. S. patent, No. 1,365,603, Jan. 11, 1921. A vapor-phase process using vertical tubes into which oil is fed at the top and the cracked vapors are taken from the bottom. This process has been very extensively tried out by a number of oil companies and individuals.

Sabatier, Paul and Mailhe, A.: U. S. patent, No. 1,124,333, Jan. 12, 1915. Crude oils are passed over finely divided catalytic metals such as tungsten, tantalum, nickel or cobalt, heated to redness by an electric current. The light unsaturated hydrocarbons obtained may be hydrogenated by contact with nickel, copper, cobalt, iron or platinum heated to 200° to 300° C.

Seigle, Adolphe: U. S. patent, No. 567,751, Sept. 15, 1896. Oil is passed through a series of vaporizing chambers and a series of superheating chambers so arranged that the oil passes through the vaporizing chambers first. Both sets of chambers are immersed in a bath of molten metal.

Shedlock, J. J., and Optime Motor Spirit Synd. Ltd.: English patent, No. 1878, Jan. 23, 1914. An emulsion of oil and water is passed through a vessel containing a catalyzer, such as iron, steel, or nickel, heated to a temperature of 260° to 480° C. The resulting vapors are expanded and condensed.

Testelin, A., and Renard, G.: U. S. patent, No. 1,138,260, May 4, 1915. Oil is heated with steam under high pressure and passed over a refractory material at red heat.

Trumble, M. J.: U. S. patent, No. 1,281,884, Oct. 15, 1918. A process in which oil is pumped at high velocity, through tubes heated in a brick furnace. Dissociation takes place in the liquid phase.

Wellman, F. E.: U. S. patent, No. 1,362,160, Dec. 14, 1920. A liquid-phase process conducted under pressure in a large horizontal tube. The vapors are fractionally condensed by passing up an inclined condenser, the portion which condenses being returned to the still.

White, C.: English patent, No. 5434, 1914. Oil is brought in a liquid state into contact with calcium oxide, or calcium oxide containing carbon, at a temperature of 400° to 600° C. Pressure is reduced to avoid formation of gas.

Young, James: English patent, No. 3345, Dec. 1865. Hydrocarbon oils are distilled. under pressure of 20 pounds per square inch.

USE OF FUEL OILS

BY

W. N. BEST

COMBUSTION ENGINEERING

Whoever contracts to design a furnace must be a man who has had years of experience in the burning of liquid fuel and must be in possession of certain data which are absolutely essential in order to design a modern furnace. If he has to design an annealing furnace, he must have the proportions of the different sections of the steel to be charged into the furnace. The metallurgist must give the designer data as to the time the metal is to remain in the furnace and the temperature which is to be maintained in the furnace during that time. With this information, the engineer should be capable of designing a furnace of the proper size, having adequate length of combustion chamber, and this chamber located in such a way as to insure a reverberation of the heat in the furnace, for heat should never be stagnant. This should be done with one burner, except in specially shaped furnaces wherein the number of burners used should not exceed two. The engineer should be able to figure accurately the oil consumption and also the air required to operate the furnace at the required temperature during the time specified by the metallurgist. If he does not know this, his efforts will fail in ninety-nine cases out of one hundred, and the manufacturer will meet with great disappointment, because of the varying quality of the product delivered from the imperfectly constructed and operated furnace. The value of steel depends upon the success of the heat treatment given it; consequently, it is absolutely essential to heat-treat the metal properly.

The author has often seen furnaces in which a certain number of burners were placed on one side of the furnace and an unequal number on the opposite side, the location of the burners being staggered. Of course the operation of this furnace was very disappointing for no one could possibly operate it successfully. The man who designed such a furnace could not be termed an engineer. To put in a number of burners, and then, if sufficient heat is not obtained, to put in a few more, is simply guess-work and not engineering. In other words, an engineer must know his business. The average manufacturer should not attempt to gamble with heat in any type or form of furnace.

There are too many engineers to-day who depend entirely upon figures secured from books or other printed matter which is considered authoritative. By using these figures they often meet with disappointment, especially in heat. There are certain fundamental principles which can be relied upon, and there are also certain data which are absolutely reliable, so reliable indeed that an engineer having them need not fail once in a thousand times in designing furnaces.

Combustion

Air contains 20.7 parts of oxygen to 79.3 parts of nitrogen. At 62° F. 1 pound of air occupies 13.141 cubic feet; at 100° F. 1 pound of air occupies 14.096 cubic feet.

Theoretically 13½ to 14½ pounds of air are required to effect the perfect combustion of 1 pound of oil. Allowing 14 pounds at 62° F., it would require 183.97 cubic feet of air to effect perfect combustion of 1 pound of oil; or at 100° F. it would require 197.34 cubic feet of air. Practically 17½ to 19½ pounds of air are required to effect perfect combustion of 1 pound of oil. Allowing 19 pounds at 62° F. this air occupies 249.68 cubic feet, or at 100° F., 267.82 cubic feet. Allowing 1 gallon of oil to weigh 7½ pounds, it practically requires 142½ pounds of air to effect the perfect combustion of 1 gallon of oil, that is 1872.88 cubic feet of air at 62° F. or 2009.25 cubic feet at 100° F.

It is essential that the liquid fuel be thoroughly atomized so that the oxygen herein referred to can freely unite with the atomized fuel. The chemical combination of this atomized fuel with oxygen disengages energy in the form of heat. The quantity or measure of this heat may be expressed in British thermal units (B.t.u.), each of which is the quantity of heat required to raise the temperature of 1 pound of water 1° F.

The air furnished for combustion contains 79.3 per cent nitrogen, the remainder being oxygen. Unfortunately, the nitrogen must be heated to the same temperature as the furnace. It is an inert gas and does not contribute to combustion but retards the violence of chemical combination; therefore it should be expelled as quickly as possible as it occupies valuable space. Hence the necessity of providing proper sized ventage in metallurgical furnaces and, modern draft gages in boiler service, in order to provide means for intelligently operating the burners and admitting just a sufficient amount of oxygen to effect combustion. It is a well-known fact that an insufficient amount of air admitted into the furnace causes imperfect combustion, forming carbon monoxide (CO). When just a sufficient amount of air for the perfect combustion of the atomized fuel is admitted into the furnace, carbon dioxide (CO_2) is produced. The absence of smoke does not always indicate perfect combustion as this may be caused by the admission of an excess of air. This results in loss of fuel since all superfluous air admitted into the furnace must be heated up to the same temperature as the furnace.

Since heat aids combustion, refractory material should be used as a firebox or furnace lining. Care must also be taken to provide simple and proper control of the supply of oil passing through the burner and of the air passing to the furnace. This is necessary in order to prevent imperfect combustion before the furnace shall have reached a temperature of approximately 1800° F. After this temperature has been attained, the regulation of the supply of air and the control of oil through the burner are much more easily adjusted.

Many engineers endeavor to compare the cost of oil as fuel with that of bituminous coal in any form of service by computing the calorific values of the two fuels. In order to show the impossibility of this, we shall consider 1 pound of bituminous coal, containing 60 per cent carbon, 25 per cent hydrocrabon gases, 3 per cent hydrogen gas, and the remainder ash. The first loss in the burning of this coal is the heat required to liberate the gases, the second is the waste of these gases after having been liberated. The calorific value of the hydrocarbon gas is approximately 440 B.t.u. per cubic foot. The coke will not contain more than 13,500 B.t.u. per pound and the hydrogen gas has a calorific value of 62,100 B.t.u. per pound. When coal is used in forges it is necessary to waste all of the volatile gases as it is impossible to weld two pieces of metal until the coal has been coked (all the gases removed); hence the loss of all of these gases, besides the time required to coke the coal. In burning oil the furnace may be operated perfectly, all the gases can be utilized in the furnace, especially the hydrogen gas which ordinarily is about 12 per cent of the oil, and the metal can be heated more quickly.

Combustion Chamber

Experience has shown that if the atomized fuel is not consumed in a combustion chamber, the furnace itself must be used for such a chamber; and in forging, heat-

treating, and melting, it is absolutely essential to have a combustion chamber of adequate proportions so that the atomized fuel will be consumed before reaching the furnace proper. Take, for example, an air furnace for melting malleable iron in a malleable iron plant. Unless the flame formed by the oil burner fits the combustion chamber, the charge will be oxidized and the silicon in the metal will be burned out. It is essential to have the combustion chamber carefully designed by a capable combustion engineer in order to prevent loss of metal and to insure absolutely perfect results from the operation of the furnace. This can readily be done. There is no need of costly experimental work for there are engineers who can design combustion chambers and furnish oil equipment by the use of which a furnace can be started daily at a given time and the metal tapped out of the furnace in a given time without a variation of ten minutes. Then a certain metal can be tapped in and the alloy desired tapped out; but without the use of a combustion chamber of the proper proportions and of a burner that makes a flame which fits the combustion chamber perfectly, it will be impossible to get these results. Often an atomizer is required which will make a long, narrow flame; for example, in large steel foundries for mold-drying. There the ovens are approximately 45 feet long, 20 feet wide and 12 feet high. The burner should therefore be able to carry a flame 12 inches in width and 45 feet in length. There are copper matting furnaces, the baths of which may be 21 feet wide by 154 feet long. For these the burner should be of sufficient capacity to produce a flame to cover the entire length and width of the bath of the furnace.

In copper refining furnaces, it is absolutely essential to use but one burner in a furnace. For example, in a copper refining furnace of 250 tons capacity, the combustion chamber must be of adequate proportions to meet the different conditions of operation for such a furnace. Copper electrodes are charged into this furnace 90 per cent pure and must leave it 99.60 per cent pure. For a number of hours after the metal becomes molten the charge is green poled; during this time the burner must be operated to give an oxidizing flame. After the metal has been brought up to a state of purity of 99.60 per cent the burner must be changed from an oxidizing flame to a perfectly neutral flame. otherwise the metal will become oxidized and the copper when made into wire will have miniature openings, thus impairing its conductivity for electrical purposes. With one burner perfect control of temperatures may be had and when it is desired to carry an oxidizing flame during the process of refining, the burner can be readily operated to give that result. Later when a neutral flame is needed after the copper has been refined and the metal discharged, the burner can be set to give a perfectly neutral flame, which with the aid of the combustion chamber gives the result desired. It is worse than folly to consider the equipment of such a furnace without the use of a combustion chamber of adequate proportions for furnace operation requirements.

Until recent years, nearly every foreman of a manufacturing works or boiler plant had a burner of his own invention. It was usually made out of pieces of pipe with the ends mashed down in a blacksmith's forge and cost about 15 cents. However, the plant owners finally became convinced that the initial cost of a burner is of small consequence compared with the cost of the oil wasted as shown by an actual test made by a competent engineer. The equipment designed by these "pipe-burner inventors," has largely vanished. Proprietors and directors have found that the efficiency attained rather than the first cost of a burner should be considered. A burner is an instrument, and usually the parts should be made to within $\frac{4}{1000}$ of an inch in accuracy in order to give results. There are few blacksmiths who can forge a piece of metal with such precision.

It must be made very plain that a burner may be perfect in construction and operation, but may prove a failure when applied to a square or oblong box-shaped old-style furnace, or when applied to a combustion chamber which has not been designed upon

scientific principles and is of inadequate proportions for the furnace. It is desired to emphasize the fact that the flame from the burner must fit the combustion chamber perfectly. There are many furnace masons who after seeing a furnace in operation with a combustion chamber of certain proportions, strive to copy it, not knowing the requirements exacted from the furnace or even the capacity of the furnace. As a result their furnaces prove failures.

Imagine, for example, a burner being placed upon a plate-heating furnace which is to heat plates to be pressed into boiler heads or boiler domes for locomotive boilers, the burner having a combustion chamber of inadequate proportions. It will be absolutely impossible to get results if these plates are not heated evenly, for when the plate is removed from the furnace and pressed into a boiler head, there will be distortion of the metal of this plate when cold which it will be impossible to remove. An oil burner can be installed in a plate-heating furnace 18 by 30 feet and give a heat which will not vary more than 15° F. in any portion of the furnace. No stack should be used on plate-heating furnaces, as stacks cause oxidation of the metal near the charging door or doors. Proper ventage of these plate-heating furnaces is very important because if the vents are too small the consumed and inert gases will be checked at the expelling end of the furnace and so cause an uneven heat in the furnace, while if the vents are too large, the result is a waste of heat, and the use of an excessive amount of oil.

Furnace designing requires the engineering service of an expert in this particular line, one who has had actual shop experience in the manufacture of the metal.

Atomization

In order to effect the perfect combustion of fuel, it is absolutely essential to provide a burner which meets the following requirements:

1. It must thoroughly atomize liquid fuel of any gravity purchasable in open market.
2. It must be capable of making a flame that will fit the fire-box or combustion chamber as perfectly as a drawer fits an opening in a desk;
3. It must have the steam opening and the oil opening independent of each other in order that high pressure will not be required on the oil line;
4. It must not carbonize. One of the most disappointing things in the world and one of the most dangerous things in a plant, is a burner which carbonizes. Therefore in the selection of a burner, great care should be taken to secure one which will not carbonize. The steam or air used for atomization should be so delivered as to strike the oil at right angles. At the same time the atomizing agent should pass over the oil orifice in order to keep the nose of the burner clean and prevent the oil from carbonizing there.
5. It must be made out of a metal having no affinity for the carbon content of the oil. It is well known to the writer that when a burner made from iron or steel is used, the carbon in the oil adheres to the metal in such a way as to fill up the entire oil orifice. It is therefore important that a certain metal alloy should be used to eliminate this difficulty.
6. It must produce a flame fitting the entire width and length of the heating chamber. In metallurgical furnace equipment for heat treatment of metal or metal melting in air furnaces in malleable iron works, it is absolutely essential to have the flame entirely span the width and length of the bath or charging space of the furnace. A burner producing a round flame will no more accomplish this than a round drawer will fit into an oblong opening of a desk.

There are thousands of burners on the market and each manufacturer claims his specific improvements over all other burners; but the above points should be considered before purchasing an oil equipment. Often oil is condemned in various services because the burner will not make a flame to cover the entire bath or charging space of the furnace. The ignorance exhibited in such oil installations is inexcusable. The oil consumer can rest assured that the failure is not the fault of the oil but of the method of its application.

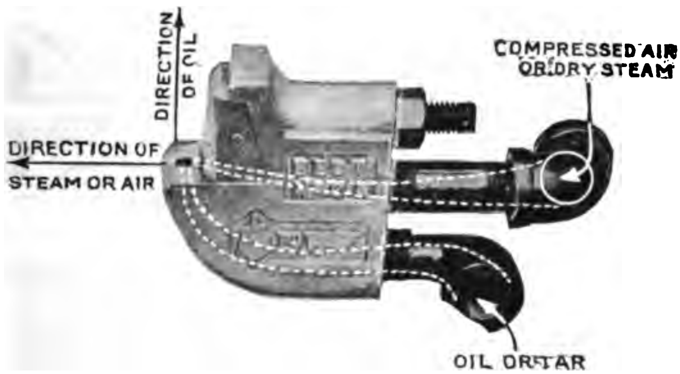


FIG. 1.—Modern high-pressure oil burner.

As the fuel passes out perpendicularly, it is struck by the atomizer coming out horizontally and is atomized so thoroughly that each drop of fuel looks like a spray and is dashed into a fine mist.

The first time a burner is operated there is usually some difficulty because of red lead, sand, scale, or small particles of solid matter in the pipes. As the fuel orifice is large anything in that line of pipe is readily expelled but as the atomizer crifice is very small (ordinarily only $\frac{1}{64}$ of an inch in height) the burner is provided with a movable lip operated by means of the locknut at the end of the burner. When this locknut is slackened and the atomizer turned on, the force of the atomizer causes the lip to move forward and frees the steam opening from any foreign substance. This burner can be filed to throw either a long, narrow flame, or a fan shaped blaze 21 feet wide by 170 feet long.

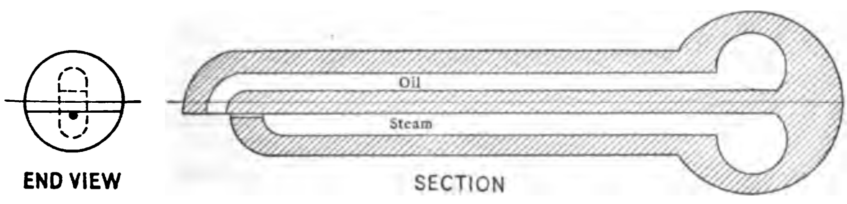


FIG. 2.

A form of atomizing burner where the stream of oil flows down upon a jet of steam and is thus carried into the firebox.

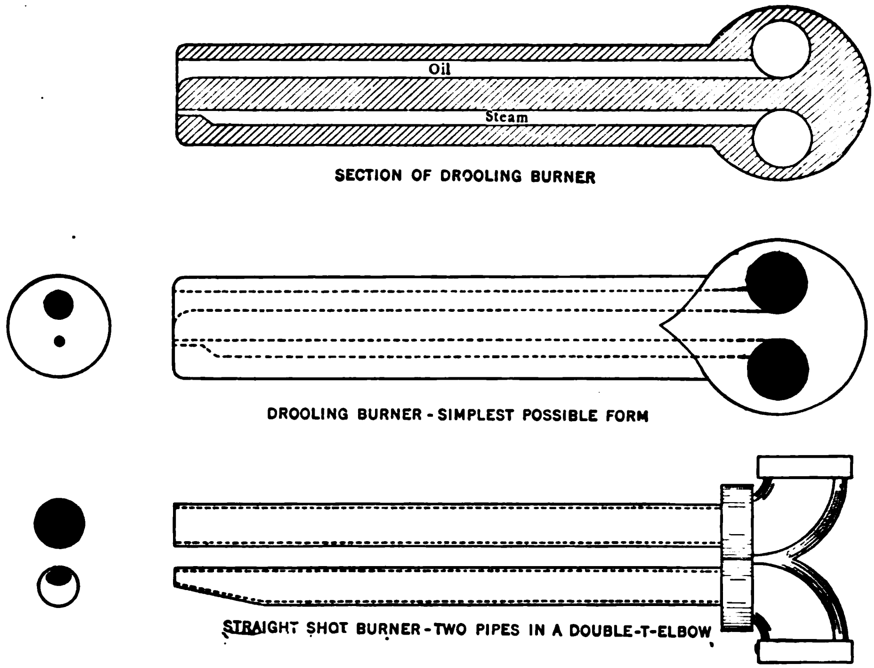
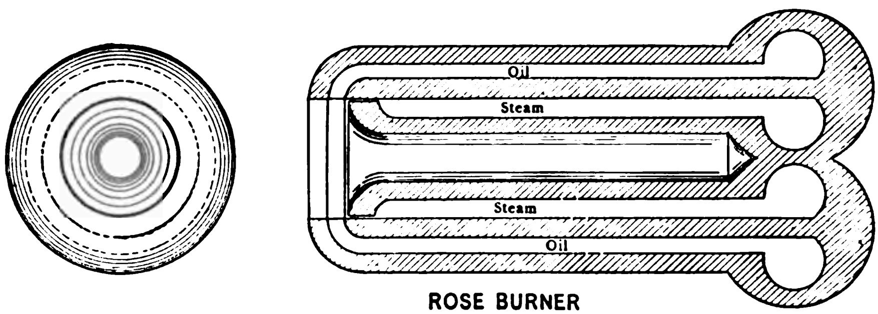


Fig. 3.

This burner is similar to the one shown in Fig. 2. The steam is below the oil, and the oil simply flows down upon the sheet of steam.



ROSE BURNER

Fig. 4.

Notice that the steam is in the inner chamber and the oil in the outer chamber. This "rose" burner makes a round flame.

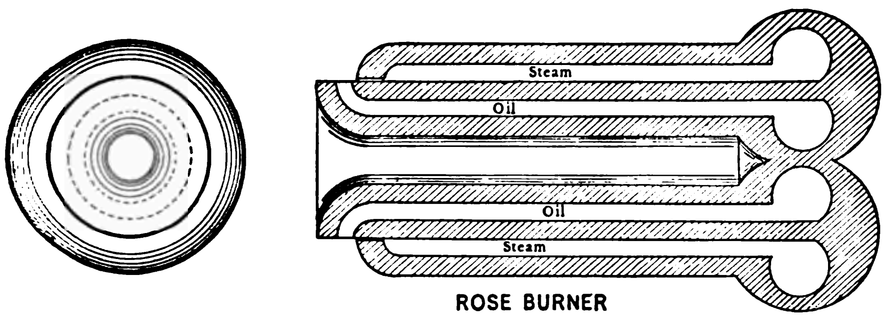


FIG. 5.

This is another form of "rose" burner where the oil is in the inner chamber and the steam in the outer chamber. This also makes a round flame. Note the impossibility of cleaning the steam orifice in this type of burner.

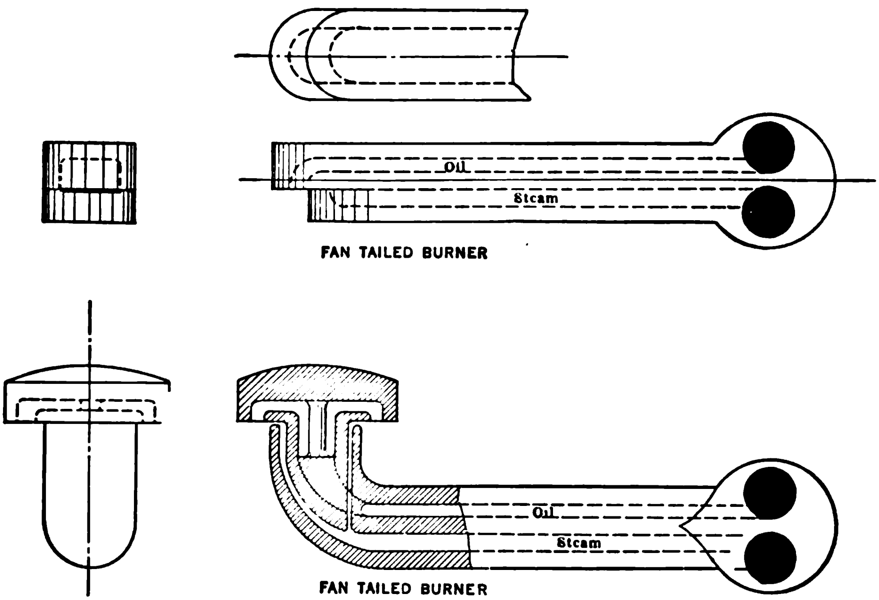


FIG. 6.—Fan-tailed cylindrical flame type of burner.

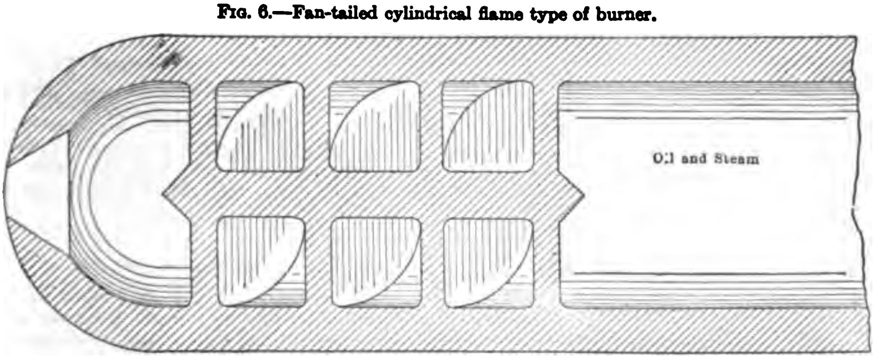


FIG. 7.—Internal-mixing centrifugal burner.

This type of burner has the oil and steam delivered as shown. The oil and steam are internally mixed in the chambers by centrifugal action caused by the form of the segments. It is readily seen that the oil pressure must be equal to the steam pressure in the operation of this type of burner.

With these later types of burners it is impossible to fit the flame to the width of the fire-box; therefore numerous burners must be used in order to get a flame which will cover the bath of the furnace.

FIG. 8.—Modern low-pressure or volume-air burner with oil-regulating cock.

The construction of this burner is such that the air supply is regulated at the mouth of the burner, thus obtaining the benefit of the full impact of the air against the fuel at the mouth of the burner.

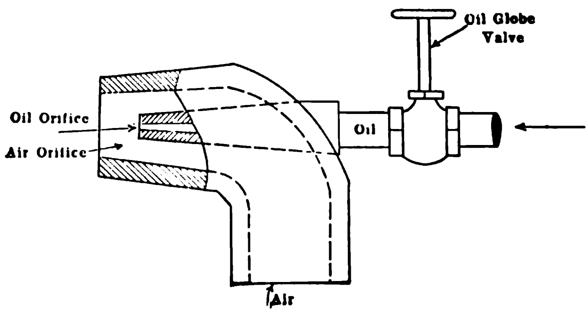
The oil flows downward through the sheet of air. Low oil pressure can be used and is preferable.

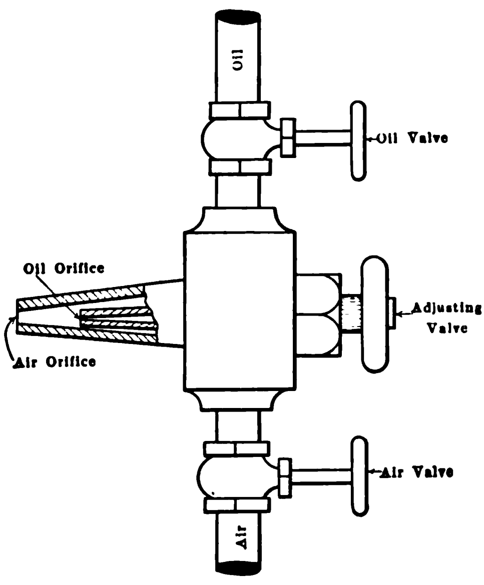
There are no internal tubes, needle points, or other mechanism to wear cut, clog, carbonize, or get out of order.

This burner is ordinarily used with light gravity oil. Note that the air atomizer lip may be adjusted so that the regulation of the air can be controlled accurately, only delivering the amount of air required for the atomization of the oil through the burner. This is necessary in the operation of the ordinary furnace. The burner is made up in different sizes adequate for various demands.

FIG. 9.

The ordinary low-pressure burner where the oil is delivered through the burner at about 40 pounds pressure and volume air is used for combustion. The oil simply squirts through the small $\frac{1}{16}$ inch opening and is burned in the furnace. Of course this type of burner can only be used for light gravity oil.





OLD TYPE OF BURNER

FIG. 10.—Another form of internal-mixing low-pressure burner.

OIL SYSTEMS

There are in general two classes of oils, one having a paraffin base and the other an asphaltum base. Oil of paraffin base is ordinarily from 28° Bé. to 36° Bé. gravity, while oil of asphaltum base varies from 11° Bé. to 32° gravity Bé. Asphaltum oil below 20° Bé. should be heated in order to reduce its viscosity so that it can be pumped readily. The oil is usually heated to 30° F. below its vaporizing point and after leaving the pump passes through an oil heater, the function of which is to heat the oil to just below its vaporizing point in order to secure from it the highest efficiency and strictest economy. Thermometers should be used on the oil line and the steam heater coil in the oil tank should be under thermostatic control. No oil system can be operated successfully unless the pumps are located properly and the piping assembled properly.

FIG. 11, page 454.—Imperfect form of oil-pumping system.

1. But one pump is used, located as shown. No reserve pump is provided.
2. There are no oil heaters or pump regulators.
3. The suction pipe is higher than the pump and is taken out of the top of the tank.
4. No combination foot valve and strainer is used with this system.
5. After the oil passes from the pump the supply pipe is raised, causing vapor pockets.
6. The oil does not circulate and the pipes are so laid as to cause a "dead end" upon the pipes.
7. The relief valve is located in the manner shown and the overflow pipe is coupled to the suction pipe of the pump.

Every part of the assemblage of this oil system is imperfect.

FIG. 12, page 455.—Modern and perfect form of oil-pumping system.

1. Two pumps are used—one for reserve. Each pump is of adequate capacity to supply oil to the two boilers.
2. The pumps are placed upon drip pans and stands, and under each pump is located a modern oil heater provided with thermometers, etc.
3. Each pump is provided with a pump regulator so that if the pressure relief valve does not function, the steam operating the pump will cause the pump to stop by means of this regulator.
4. Pulsometers are provided, their function being to remove pulsations of the pump.
5. A combination foot valve and strainer is provided in the tank.
6. A heater is provided in the tank to heat the oil to reduce its viscosity if the oil is below 20° Bé. gravity.
7. The oil supply pipe circulates the oil so that there are absolutely no "dead ends," and if the oil must be heated, it can be delivered to all the boilers at the temperature required.
8. The relief valve is located at the last boiler in the battery and the oil overflow pipe from the relief valve passes back into the tank independently of any other pipe line, and does not couple to the suction pipe of the pump.
9. The suction pipe, the oil supply pipe to the burners, and the overflow pipe are provided with a steam pipe running parallel with and immediately under these pipes in order to reduce the viscosity of the oil remaining in these pipes and to keep it in a fluid state. This is very necessary, especially when the plant is shut down over Sunday, for the oil in the suction, supply, and overflow pipes will acquire a jelly-like consistency if this steam heater pipe is not provided.

This system shows but two boilers in battery, but as many as forty-six may be included in one system. In fact, systems 6000 feet in length have been used.

FIG. 13.—Modern pumping system provided with heaters immediately under pumps.

In usual practice both pumps exhaust into one heater and the other heater may be connected with live steam from the boiler in order to insure the heating of the oil to the proper temperature. Live steam, however, is only used when heating heavy viscous oils. Sometimes the exhaust of the steam pipe is insufficient to heat the oil to the required temperature.

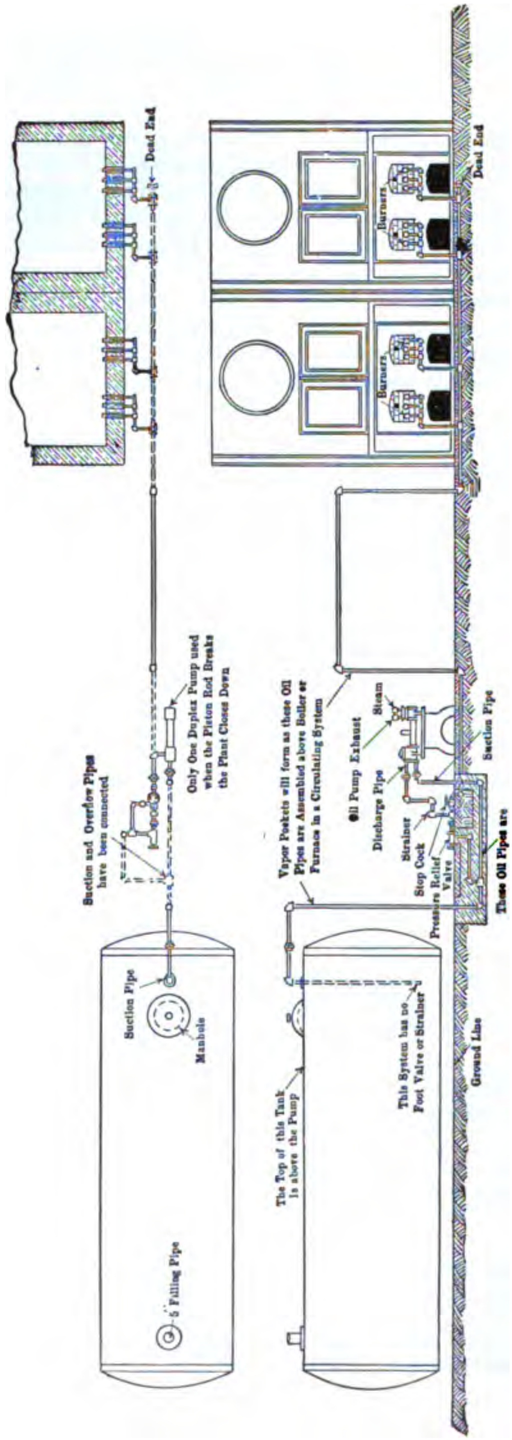

Suction and Overflow Pipes have been connected
Dead End
Only One Duplex Pump used when the Piston Rod Breaks the Plant Closes Down
Burners
Burners
Dead End
Vapor Pockets will form as these Oil Pipes are Assembled above Boiler or Furnace in a Circulating System
Steam
Oil Pump Exhaust
Discharge Pipe
Strainer
Stop Cock
Pressure Relief Valve
These Oil Pipes are Laid Level
Suction Pipe
Suction Pipe
Manhole
5' Filling Pipe
The Top of this Tank is above the Pump
This System has no Foot Valve or Strainer
Ground Line

Fig. 11.

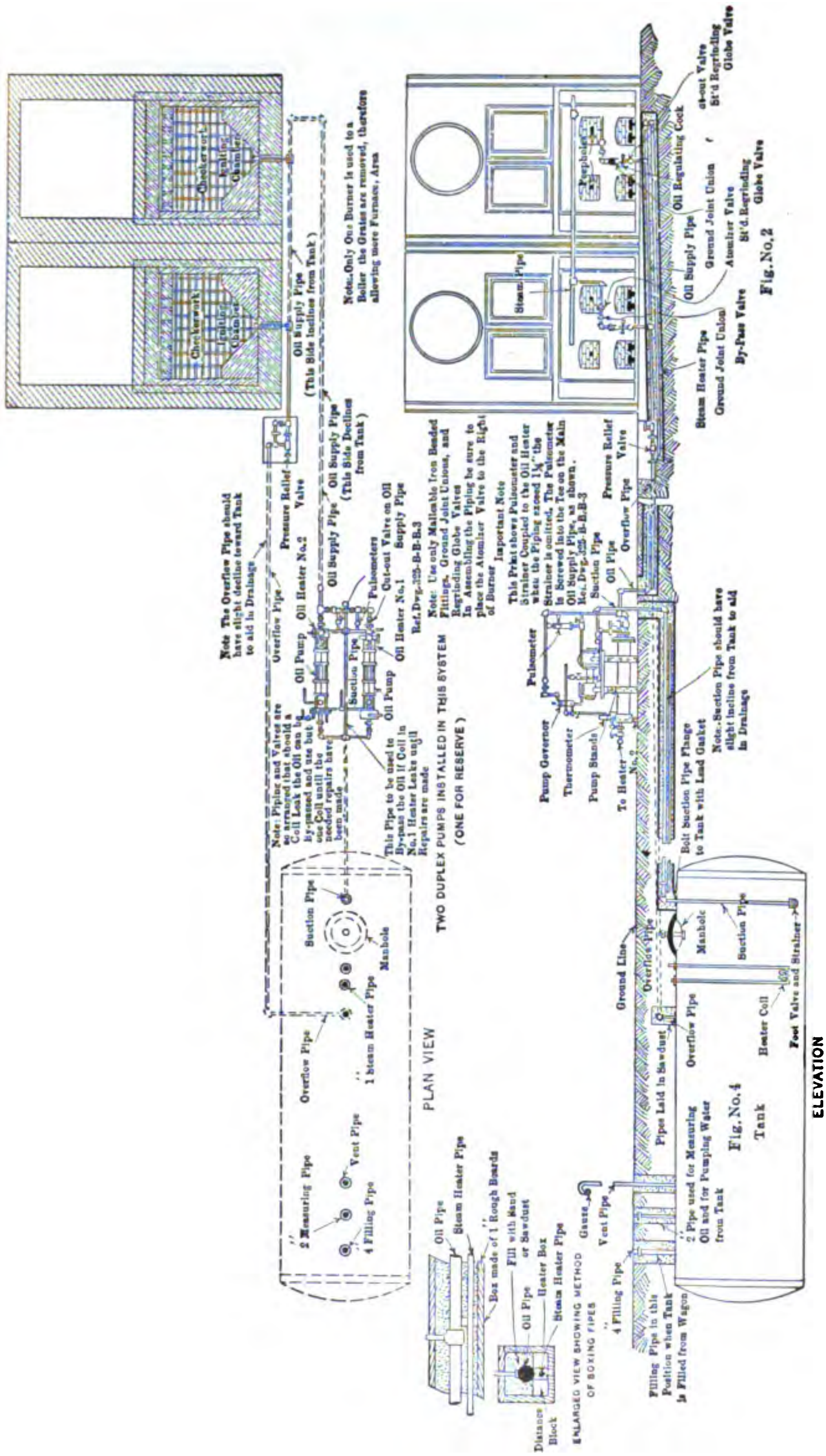
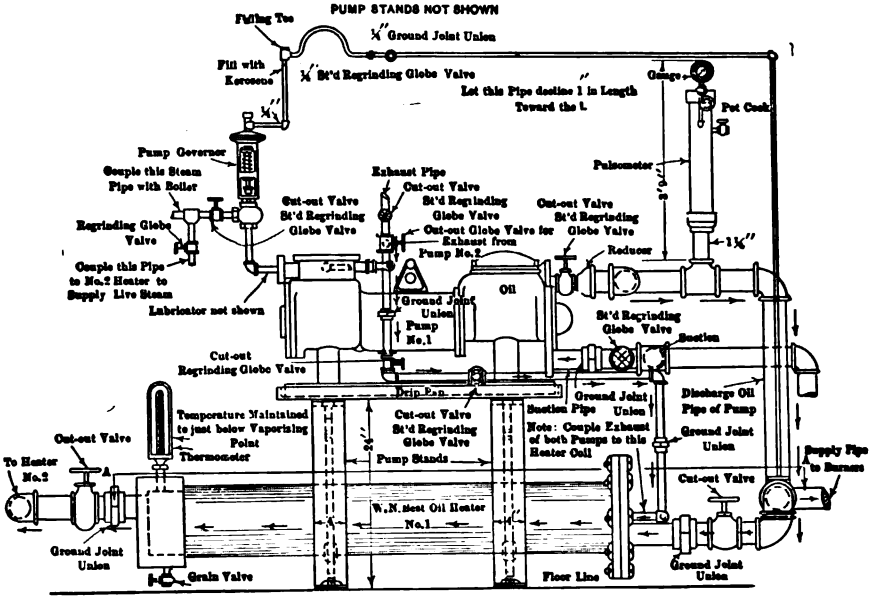

PLAN VIEW
TWO DUPLEX PUMPS INSTALLED IN THIS SYSTEM
(ONE FOR RESERVE)
ENLARGED VIEW SHOWING METHOD OF BOXING PIPES
Fig. No. 2
Fig. No. 4
Tank
ELEVATION

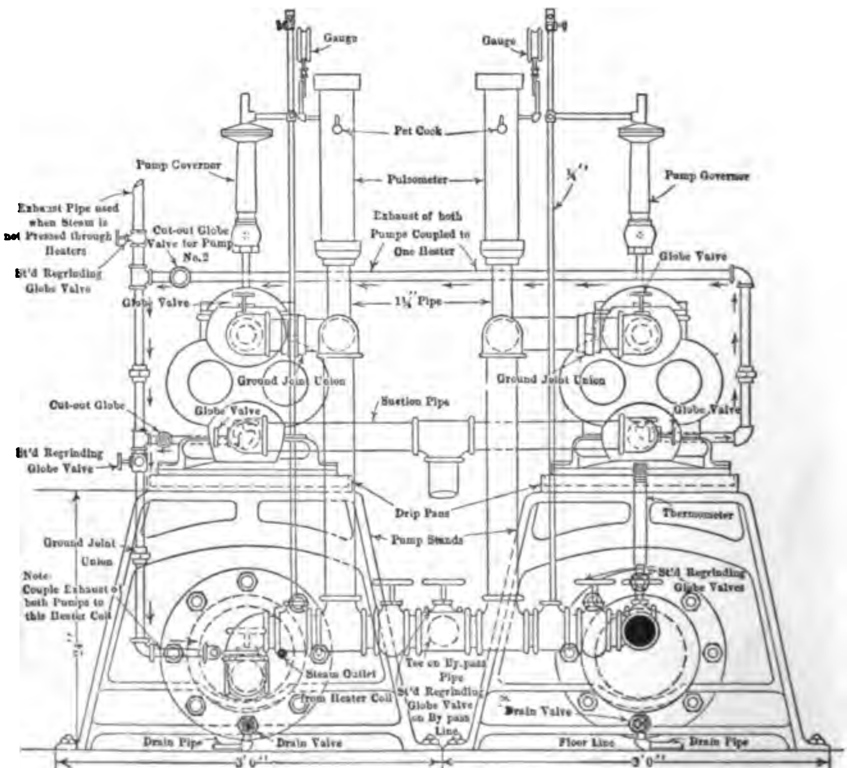
FIG. 12.

SECTION AT A-A
PUMP STANDS NOT SHOWN



ELEVATION OF PUMPS AND HEATERS

Fig. 13a.



END VIEW OF PUMP AND HEATERS
(PULSOMETER END)

Fig. 13b.

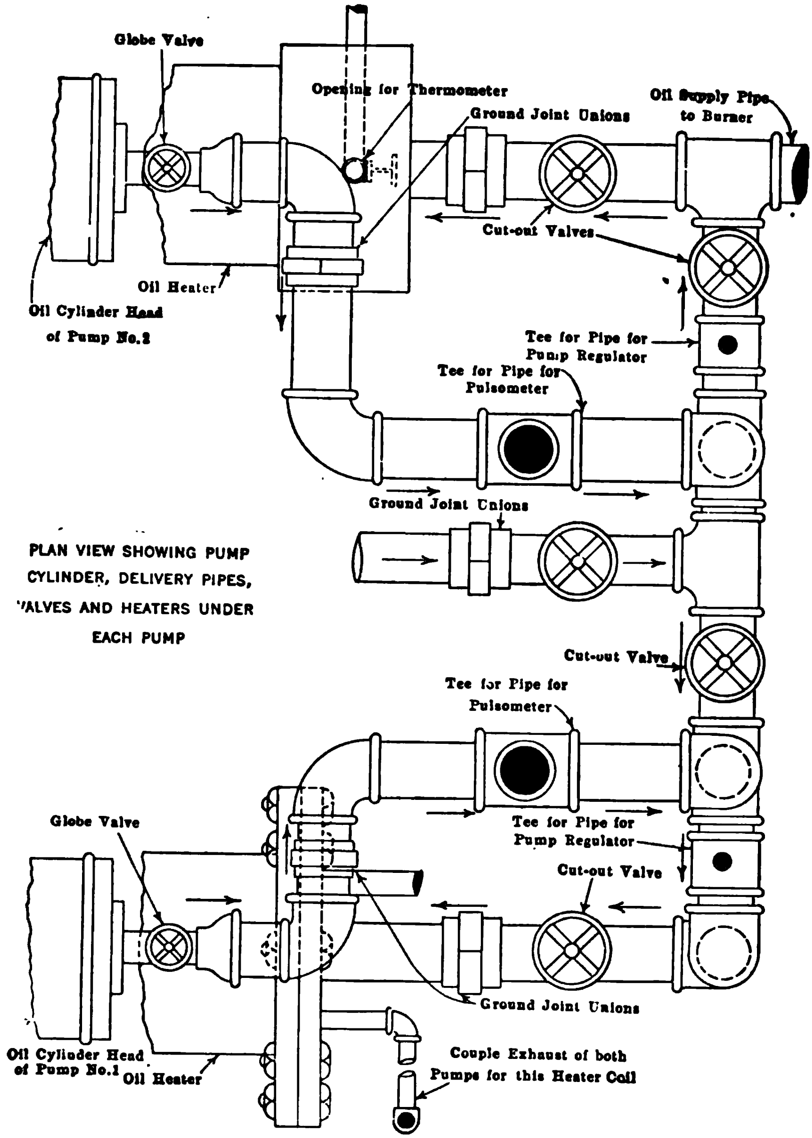

Globe Valve
Opening for Thermometer
Ground Joint Unions
Oil Supply Pipe to Burner
Cut-out Valves
Oil Heater
Oil Cylinder Head of Pump No.2
Tee for Pipe for Pump Regulator
Tee for Pipe for Pulsometer
Ground Joint Unions
PLAN VIEW SHOWING PUMP CYLINDER, DELIVERY PIPES, VALVES AND HEATERS UNDER EACH PUMP
Cut-out Valve
Tee for Pipe for Pulsometer
Globe Valve
Tee for Pipe for Pump Regulator
Cut-out Valve
Ground Joint Unions
Oil Cylinder Head of Pump No.1
Oil Heater
Couple Exhaust of both Pumps for this Heater Coil

FIG. 13a

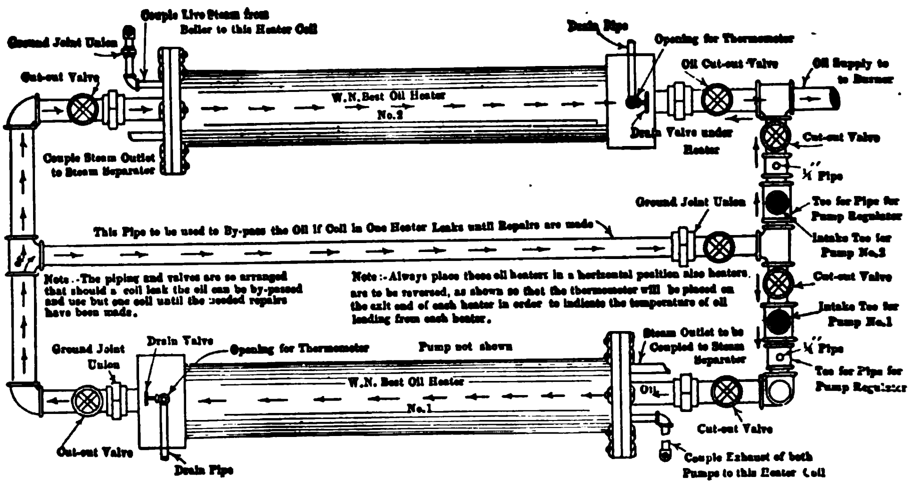
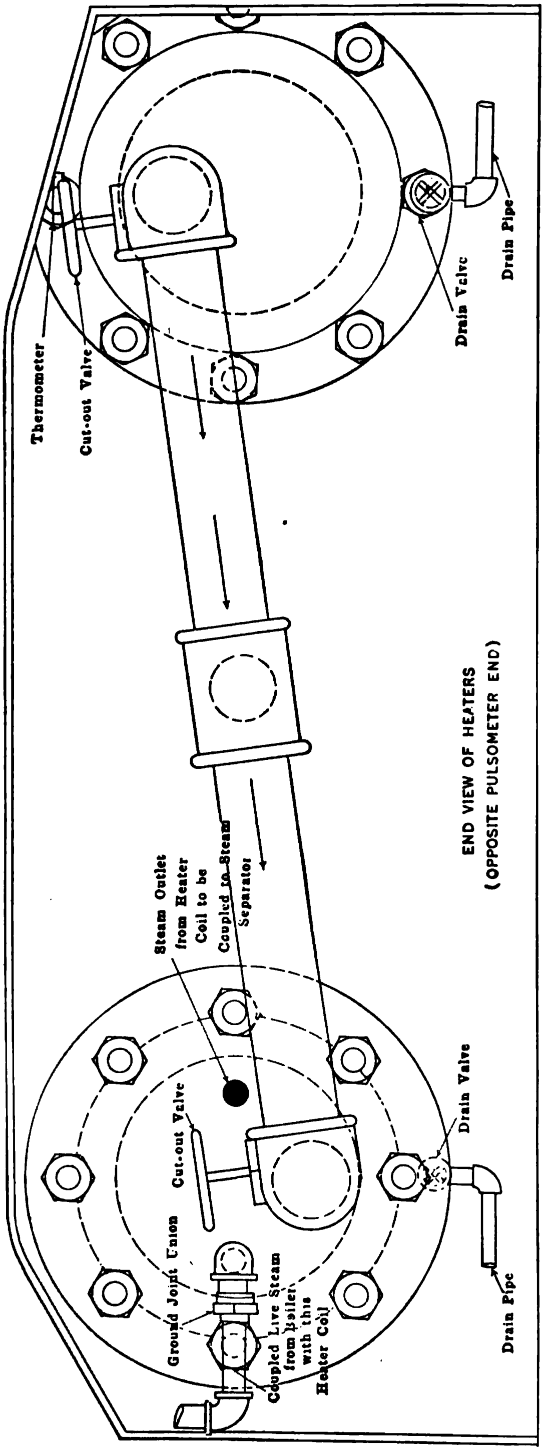

Couple Live Steam from
Boiler to this Heater Coil
Ground Joint Union
Cut-out Valve
W.N. Best Oil Heater
No. 2
Couple Steam Outlet
to Steam Separator
Drain Pipe
Opening for Thermometer
Oil Cut-out Valve
Oil Supply to
to Burner
Drain Valve under
Heater
Cut-out Valve
¼″ Pipe
Ground Joint Union
Tee for Pipe for
Pump Regulator
Intake Tee for
Pump No. 2
This Pipe to be used to By-pass the Oil if Coil in One Heater Leaks until Repairs are made
Note.-The piping and valves are so arranged that should a coil leak the oil can be by-passed and use but one coil until the needed repairs have been made.
Note:-Always place these oil heaters in a horizontal position also heaters are to be reversed, as shown so that the thermometer will be placed on the exit end of each heater in order to indicate the temperature of oil leading from each heater.
Cut-out Valve
Intake Tee for
Pump No. 1
¼″ Pipe
Tee for Pipe for
Pump Regulator
Steam Outlet to be
Coupled to Steam
Separator
Ground Joint
Union
Drain Valve
Opening for Thermometer
Pump not shown
W.N. Best Oil Heater
No. 1
Oil
Cut-out Valve
Drain Pipe
Cut-out Valve
Couple Exhaust of both
Pumps to this Heater Coil

FIG. 184.



END VIEW OF HEATERS
(OPPOSITE PULSOMETER END)

FIG. 13e.

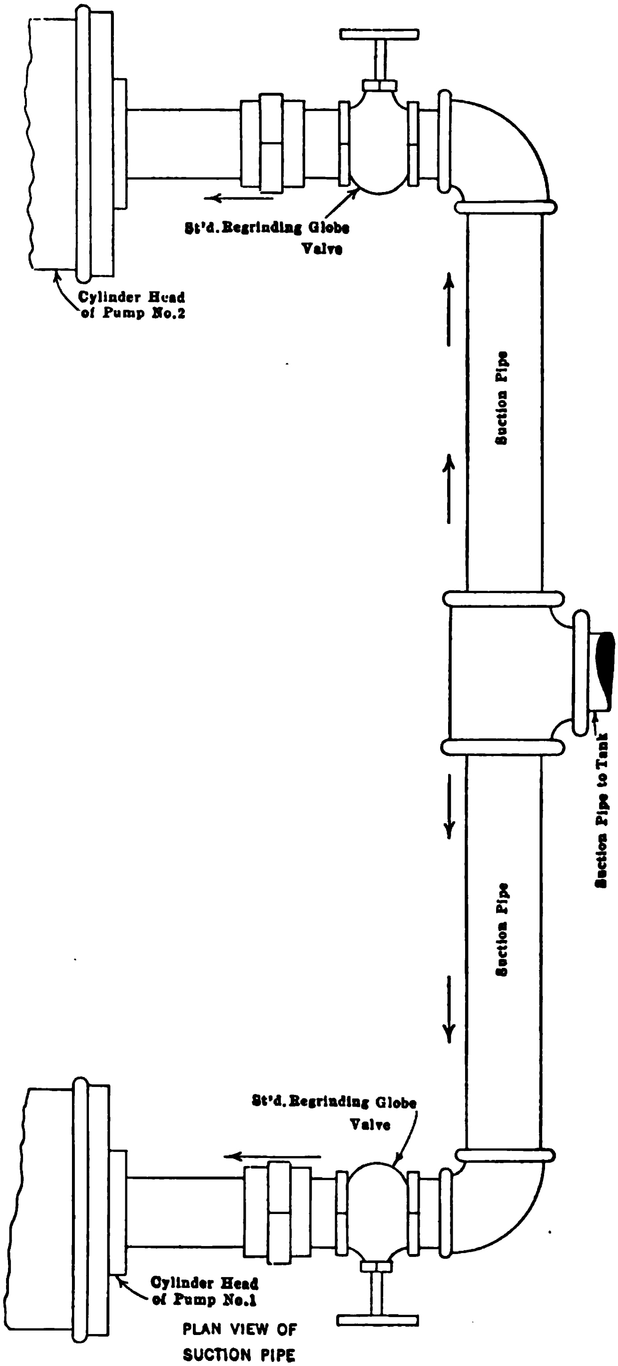

St'd. Regrinding Globe Valve
Cylinder Head of Pump No. 2
Suction Pipe
Suction Pipe to Tank
Suction Pipe
St'd. Regrinding Globe Valve
Cylinder Head of Pump No. 1
PLAN VIEW OF SUCTION PIPE

FIG. 137.

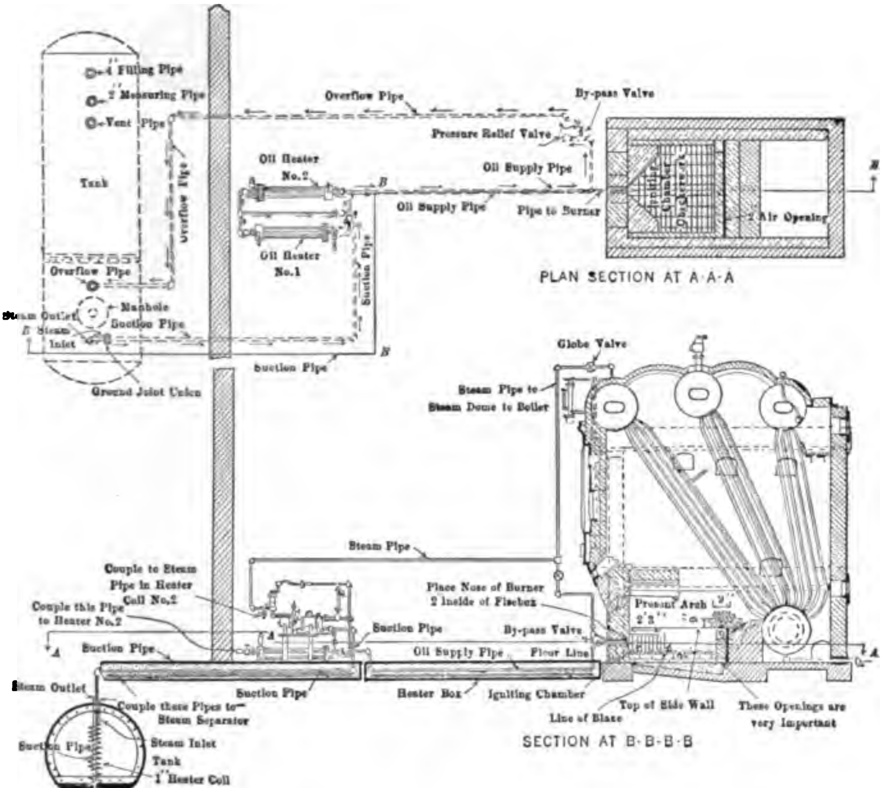


Fig. 14.—Diagrammatic oil layout for only one boiler.

One view shows the pumps in position immediately over the heaters; while in the mid-section view the pumps are removed and only the heaters shown, to illustrate the assemblage of the pipes more clearly.

Fig. 15.—A pressure relief valve ordinarily placed on the end of the oil-supply pipe to the burners to maintain 12 pounds pressure on the oil line.

Fig. 16.—Pump speed regulator which is attached to the steam connection of the oil pump. Should the relief valve refuse to function and the oil pressure increase from, say, 12 to 14 pounds, this pump regulator will automatically shut off the supply of steam from the pump so the pump will instantly cease operating.

Fig. 17.—Combination foot valve and strainer used at the bottom of the suction pipe in oil tanks.

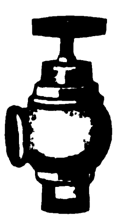


Fig. 15.

Fig. 16.

Fig. 17.

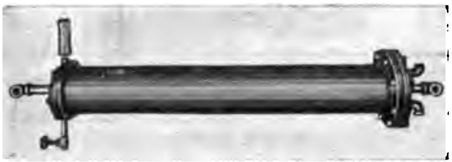


FIG. 18.
Modern oil heater used in the heating of oil, ordinarily placed immediately under the pump as shown in Fig. 13.

FIG. 19.—Pulsometer with gage.

FIG. 21.—Oil regulating cock.

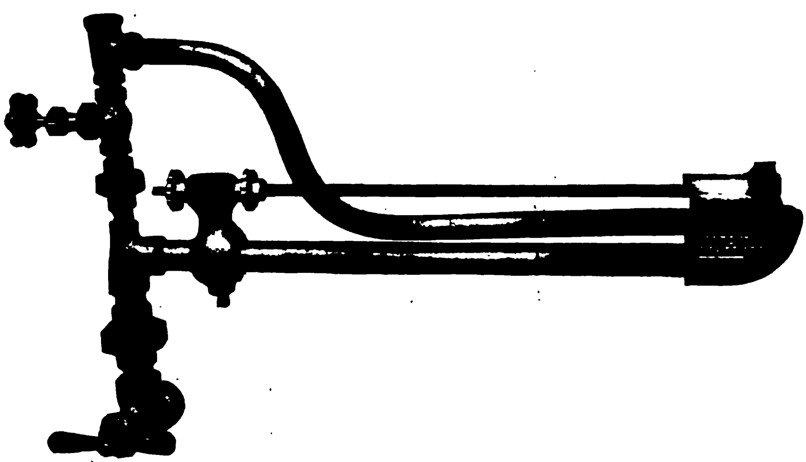


FIG. 20.—Oil burner mounted for boiler.

Oil Equipment for Stationary Boilers

In Fig. 22 the boiler has been changed from coal firing to oil. It is always necessary to cut down the bridge wall and protect the blow-off cock pipe with brick, substantially as indicated in the above drawing. In assembling the pipes, always assemble the oil-regulating cock to the left, and the atomizer valve to the right-hand side of the burner.

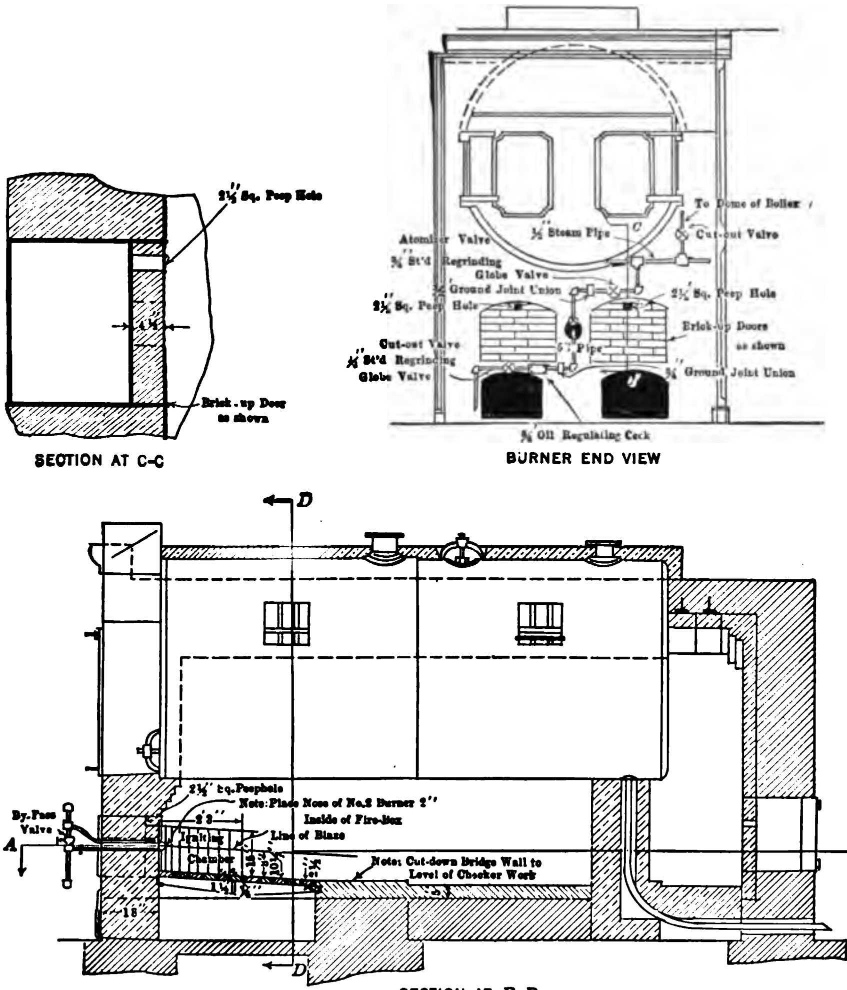


Fig. 22.—Old-fashioned or low setting for horizontal return tubular boiler.

The ignition chamber must be built V-shaped, as shown. Do not change the form under any circumstances, as the flare of the sides must begin at the burner opening.

Only malleable iron beaded fittings, ground-joint unions, and regrinding globe valves should be used.

In building the furnace use only A, No. 1 non-expanding standard firebrick, such as are made by the Harbison-Walker Company, or their equivalent.

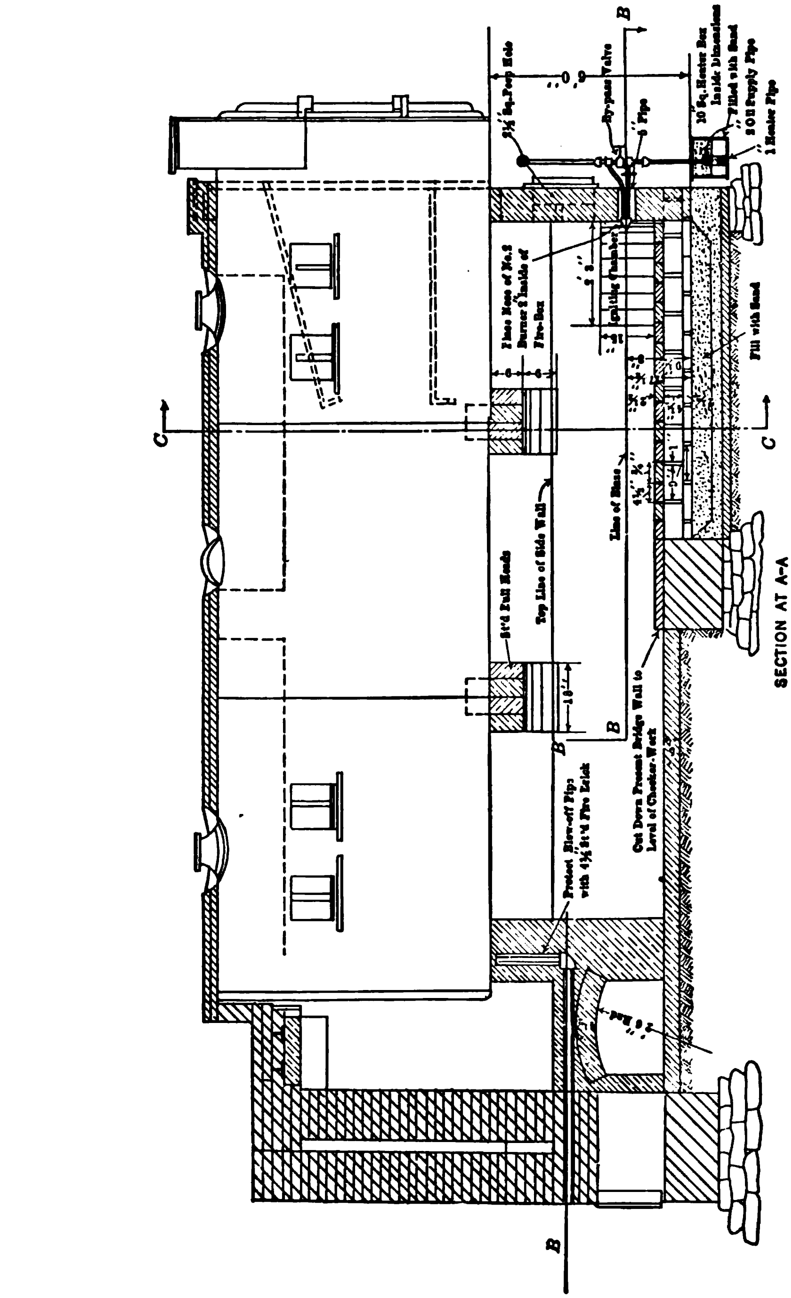


Fig. 23.—Horizontal return tubular boiler, high setting.

The largest possible furnace area is always recommended. Therefore it is preferable that the grates be removed and a checker work of firebrick placed in the manner shown in Figs. 23 and 23*a*.

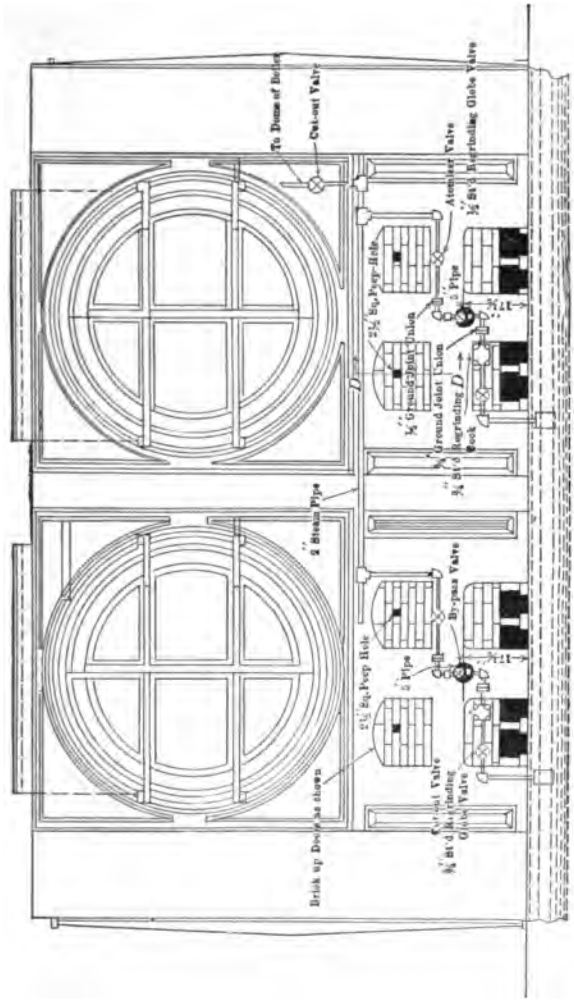


Fig. 23*a*.—Horizontal return tubular boiler, high setting.

As before stated, it is modern practice to get as large furnace volume as possible. Often the bottom of the boiler shell is placed 10 feet above the grates as shown in Fig. 24.

The lap seam of the boiler is protected by a brick arch as shown, and the blow-off cock pipe is also protected in the manner indicated

It will be noticed that the bridge wall is cut down to the level of the checker work which covers the grates and an ignition chamber is used to prevent any explosion of gas in the firebox. Often oil and tar contain some water, and this ignition chamber which becomes excessively hot provides means for igniting the oil after a pocket of water has passed through the burner. With this ignition chamber the flame is ignited at the burner after the pocket of water has passed away, but without the use of this chamber

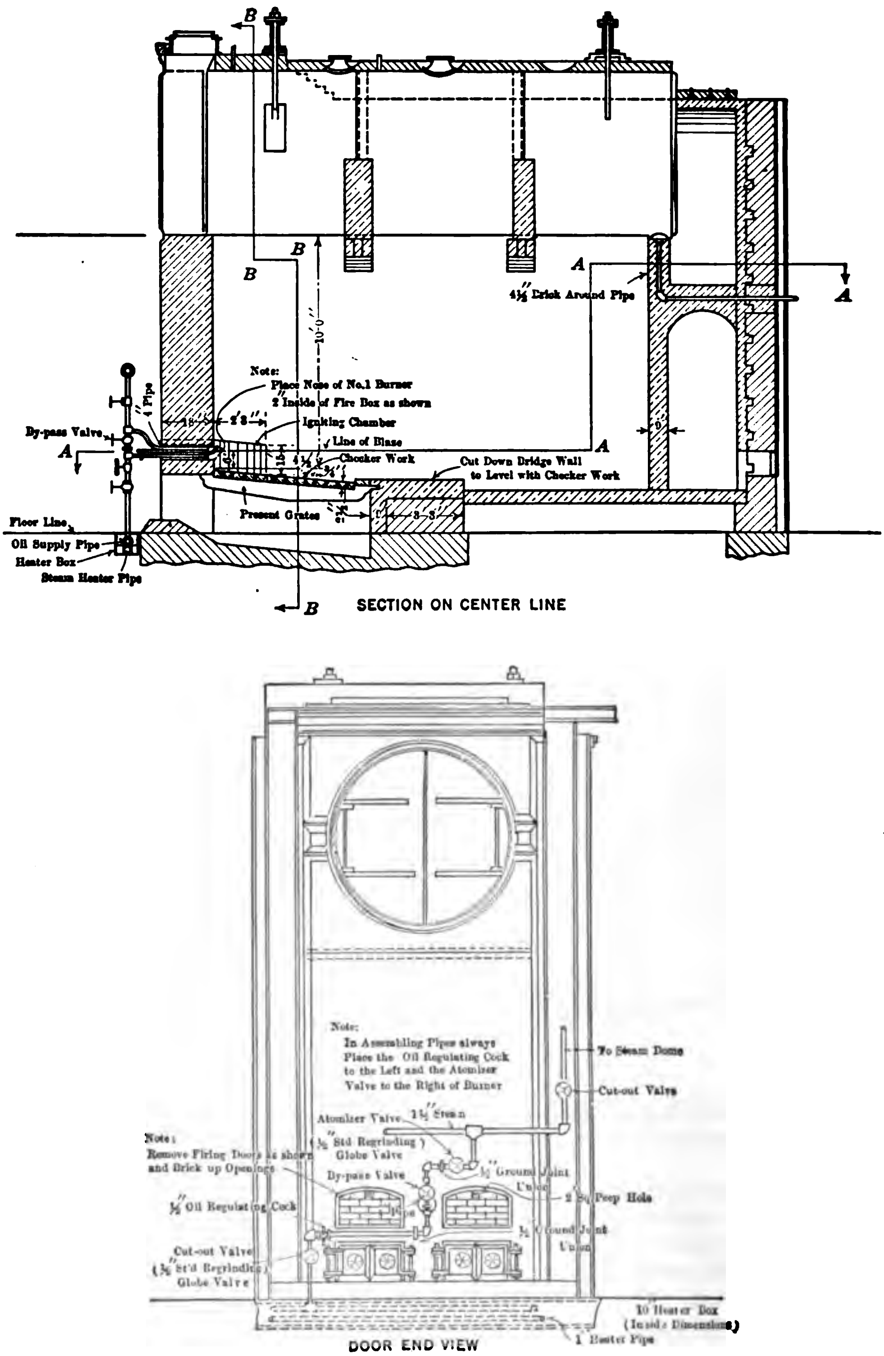


FIG. 24.—Return tubular boiler, high setting, which is recommended when placing a new boiler.

the vapor does not usually ignite until the firebox is filled with vapor which finally explodes and often blows the doors open and the brick out of the doors. This is avoided when using an ignition chamber.

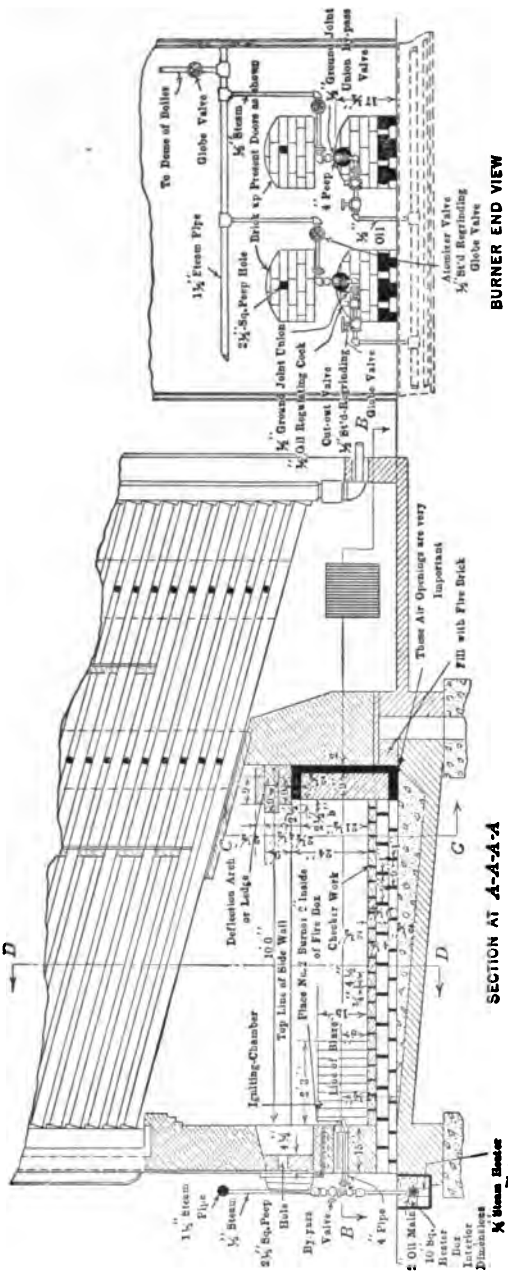


FIG. 25.—Low setting Babcock & Wilcox boiler, having long firebox.

Fig. 26 shows a rather high setting for a Babcock & Wilcox boiler, but to-day the elements are being placed as high as 14 feet above the grates, which insures the highest efficiency and strictest economy of the fuel. Again, it obviates the difficulty often occasioned by a small furnace area when the boiler is called upon to operate at 200

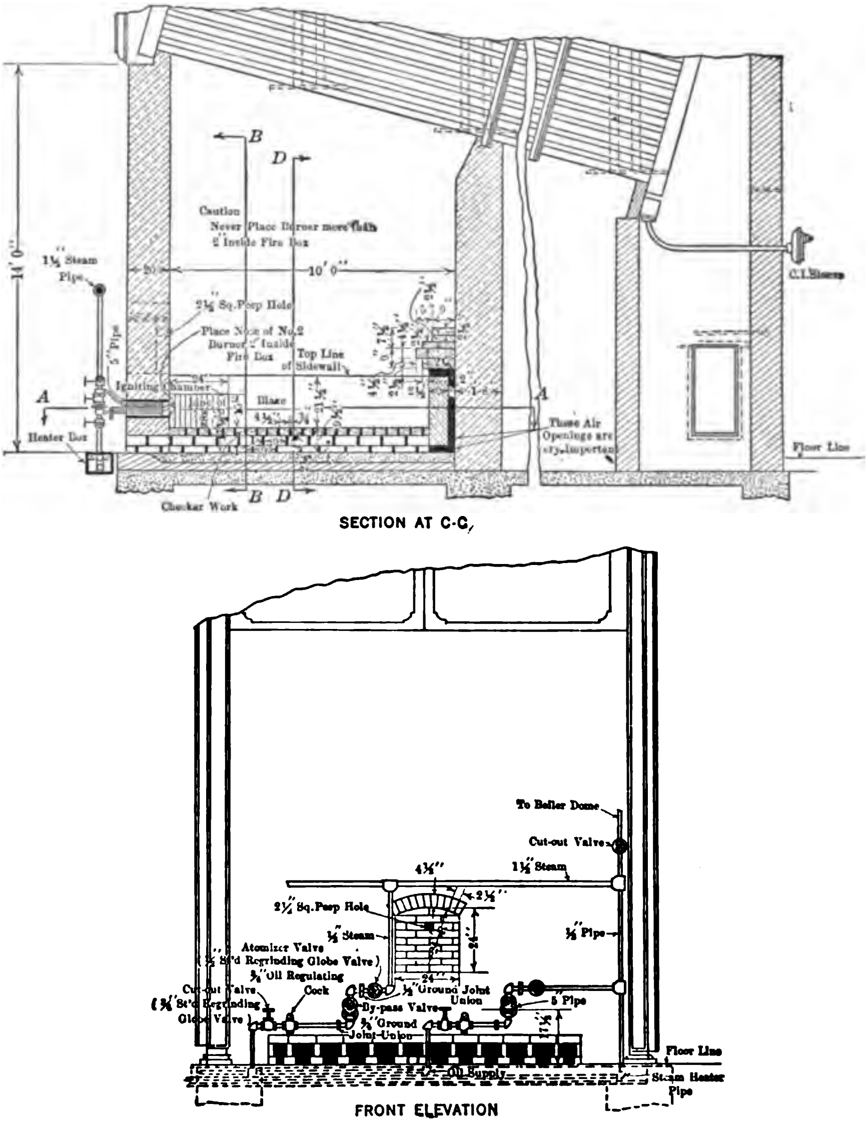


FIG. 26.—B. & W. boiler equipment, front end view showing location and piping of burners.

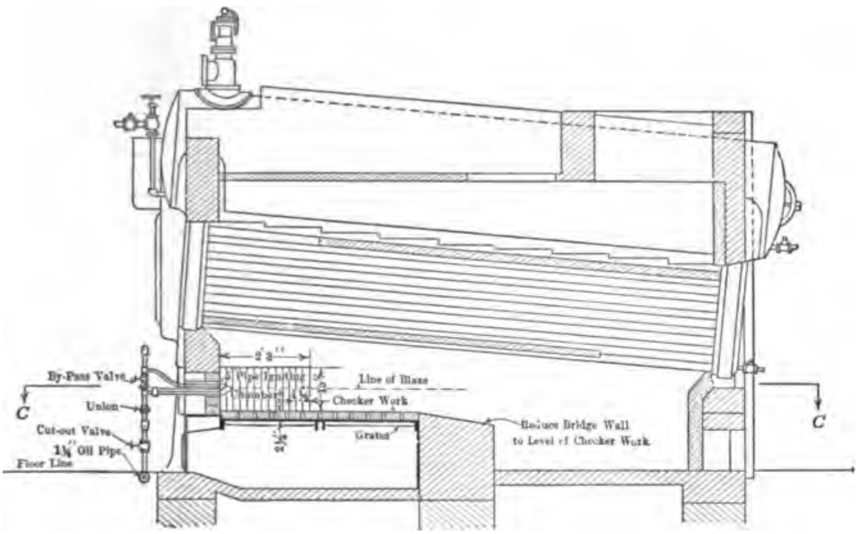
per cent rating. This often results in blistering the tubes because of excessive temperature in the firebox.

By using a large furnace area, velocity is reduced and better heat is obtained by the radiation from the firebrick of the furnace. In other words, greater economy in fuel

can always be obtained by having the elements of the boiler high and the furnace area deep.

In the equipment shown in Fig. 27 the bridge wall is cut down and the grates remain in their usual position. The checker work of firebrick covers the grates simply for their protection, and an ignition chamber is built in the manner shown. The air for combustion passes up through the grates and the space between the rows of checker work. Note that the grates are only 24 inches below the elements of the boiler, which of course does not give sufficient furnace area for high ratings, for if high ratings are attempted from a boiler with such small furnace area, it simply means that the intense heat of the flame from the burner will melt the firebrick and may cause blistering of the tubes.

The firebox of the boiler in Fig. 28 is of larger area and the distance between the elements and the burner is much larger than in the boiler shown in Fig. 27. With this furnace area 200 per cent rating can readily be attained and maintained without destroying the firebrick or blistering the tubes of the boiler.



SECTION AT A-A

Fig. 27.—Heine boiler, low setting.

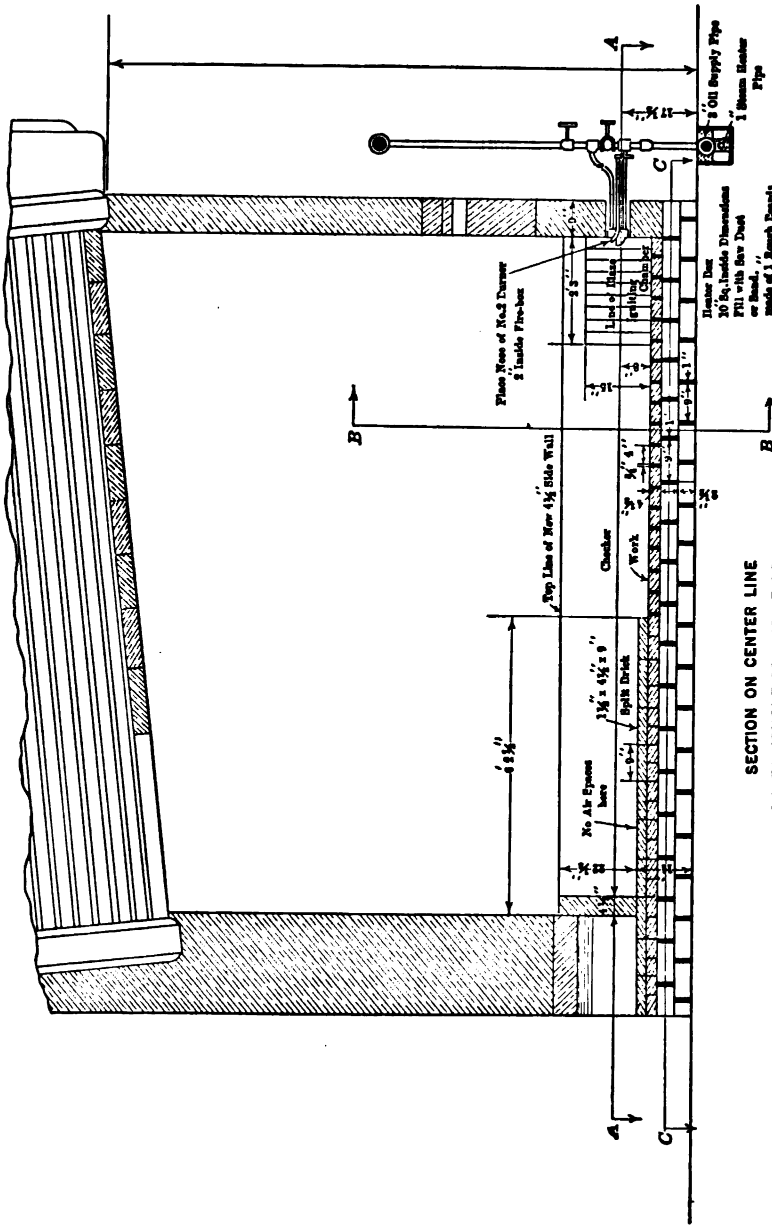
A few years ago engineers were under the impression that in order to get high efficiency out of the fuel, the elements of the boiler had to be near the fuel, but experience has taught that this is not so.

Comparing these two Heine boilers, it is evident that 1 pound higher evaporation per pound of fuel can be obtained by the use of the high setting than with the low setting.

The burner in Figs. 29 and 29*a* is so placed that the flame will be directed towards the firing door of the boiler in order to have the entire firebox filled with flame and heat. The operating valves are placed in a position convenient to the operator at the firing-door end of the boiler.

An arch is sprung over the flue-sheet end of the boiler. This is necessary in order to prevent short circuiting of the heat when the burner is operated at its minimum capacity.

If it is desired to raise steam in this boiler, a small amount of wood is charged in through the firing door, as when starting a coal fire; after 5 pounds of steam have been secured, the burner is operated. The position of the burner (see Fig. 30) is such that it does not have to be removed when the boiler is being fired up.



SECTION ON CENTER LINE
OIL EQUIPMENT FOR HEINE BOILER

FIG. 28.—Heine boiler, high setting.

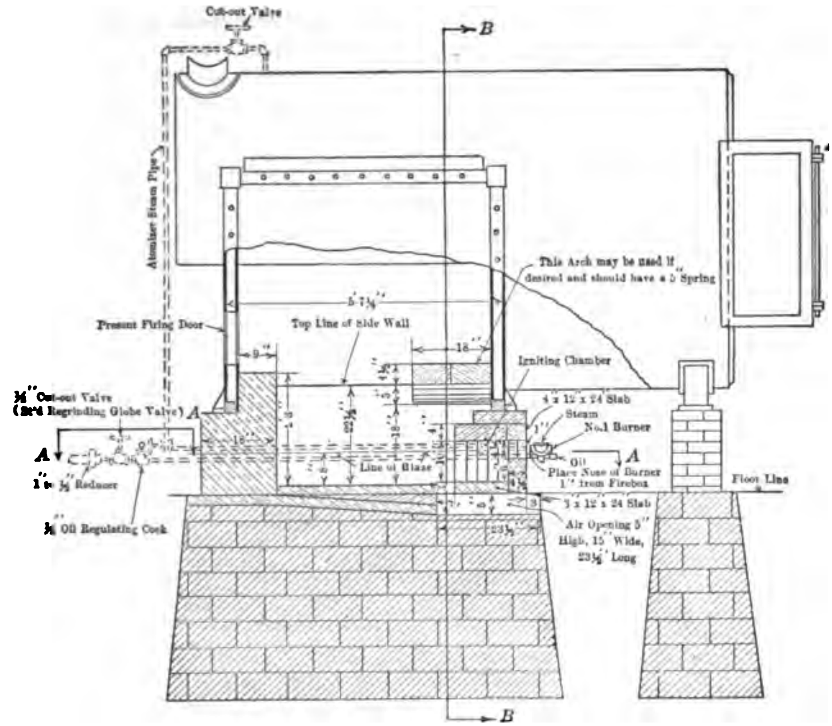


Fig. 29.—Economic type boiler.

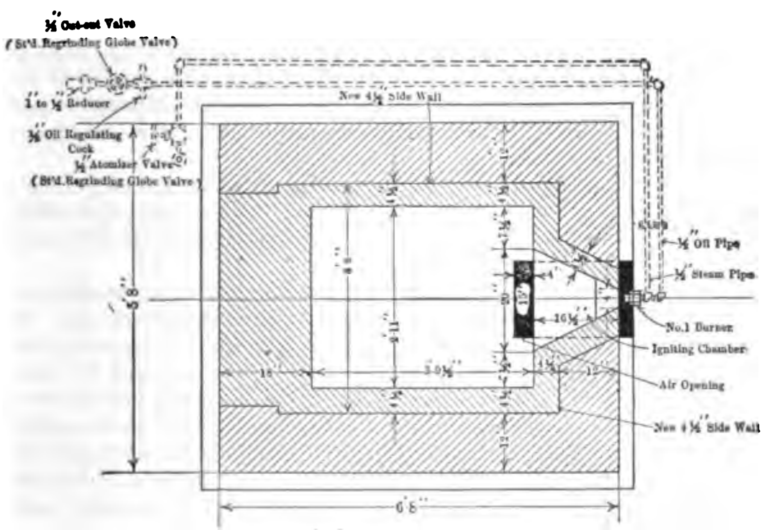


Fig. 29a.—Plan view showing piping and arrangement of refractory material in Economic type of boiler.

The burner is placed at the flue-sheet end of the boiler shown in Fig. 31. The equipment is much the same as that for an Economic type of boiler.

Fig. 32 shows a hand-fired boiler equipped to burn oil in combination with coal. Often, however, stoker-fired boilers are equipped for oil in like manner for the same purpose.

In some sections of the country oil is too expensive to use exclusively in power plants, and is therefore only used to meet peak loads; therefore the use of the fluid injecting apparatus is recommended. It is ordinarily placed in the side wall of the boiler in the manner indicated.

The opening in the side wall of the firebox should be, if possible, centrally located, between the front end setting and the bridge wall. If a boiler brace conflicts, place the opening in the side wall toward the front end setting. Make the bottom of the opening 2 inches above the highest coal level used on the boiler; size of opening 15 inches wide flaring to 34 inches, height of opening 13½ inches.

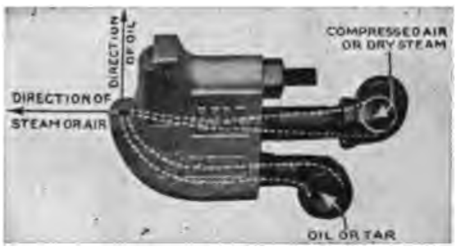


FIG. 30.—Type of burner used in the equipment of Economic boilers.

In the testing of oil for its gravity, the chapter on Testing Methods should be consulted.

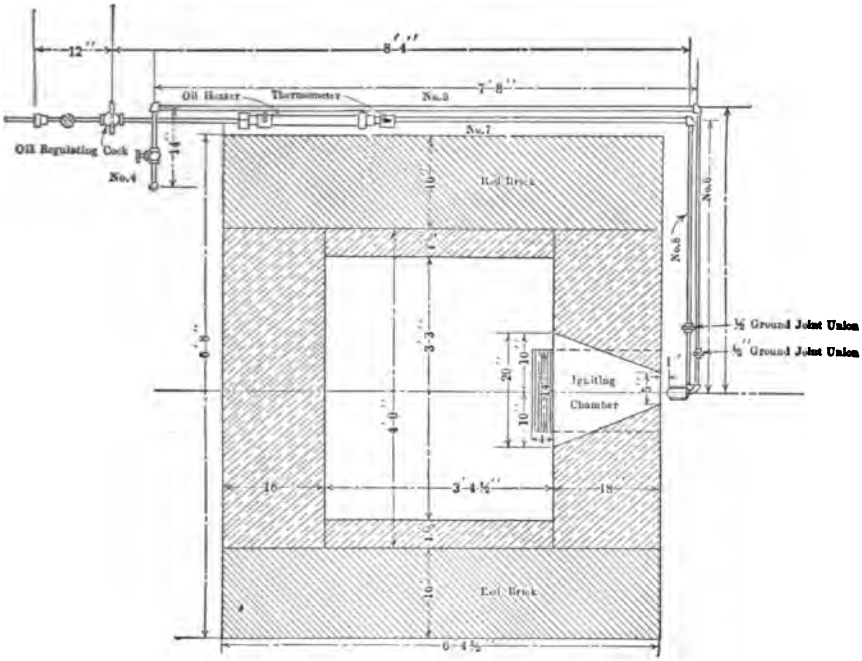
Instruments for gaging the quantity of oil passing to the burners and the temperature of oil delivered to the burners, CO_2 recording instruments, draft gages, steam flow meters, etc., are recommended. (See Figs. 33, 34, 35 and 36.)

This new type of combination gage is the most universal differential draft gage devised, and for air supply control is the simplest and most valuable instrument yet introduced. Considering it on a basis of true efficiency, first cost, attention required and maintenance, it surpasses all other combustion instruments. It is the biggest value ever offered for the boiler room.

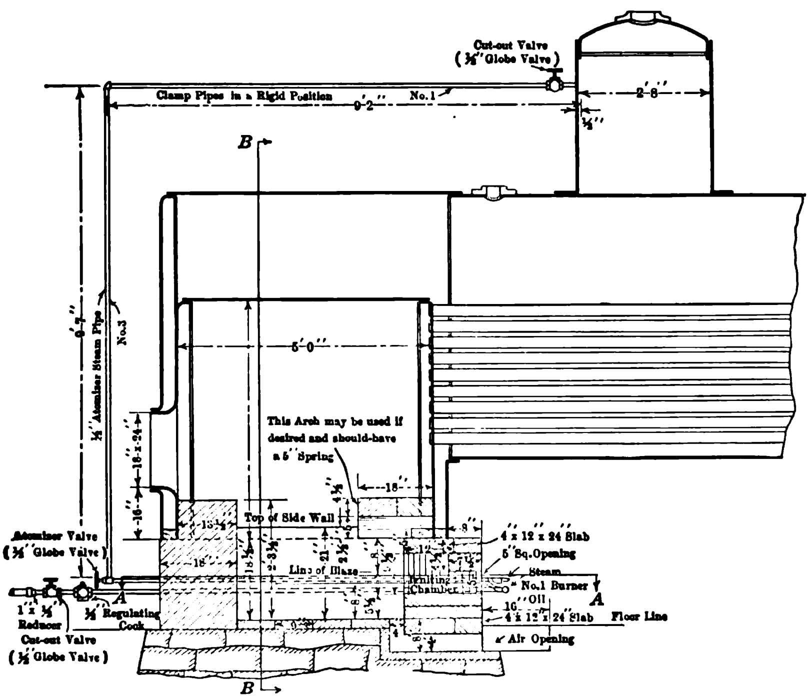
By a simple and ingenious system of cross-piping the cover type differential gage, a type has been developed whereby the furnace draft, the flue draft or the differential between the flue and furnace can be indicated on a single gage over the full length of the scale.

As the differential gives a greater liquid movement for a given variation in air supply than the furnace draft the gage is operated continuously on the differential. The ordinary draft gage, when connected either to the furnace or to the flue, indicates only a difference in pressure between the furnace or the flue and the outside of the setting, and does not serve as a reliable guide to the actual amount of air passing through the furnace.

The air to an oil-burning furnace can be regulated in two ways, by the ash-pit doors and by the damper. With the ash-pit doors wide open and the air regulated by the damper, the ordinary type draft gage serves very well as an indicator of the amount of air passing through the setting; but should these conditions be reversed, that is, the damper wide open and the ash-pit doors partly closed, the indications of the ordinary type draft gage are of no value whatever, inasmuch as closing the ash-pit doors tends to cut down the air and at the same time indicates a higher draft pressure.



Plan view showing position of burner and piping required when a locomotive boiler is used in stationary service.



SECTION ON CENTER LINE

Fig. 31.—Locomotive boiler used in stationary service.

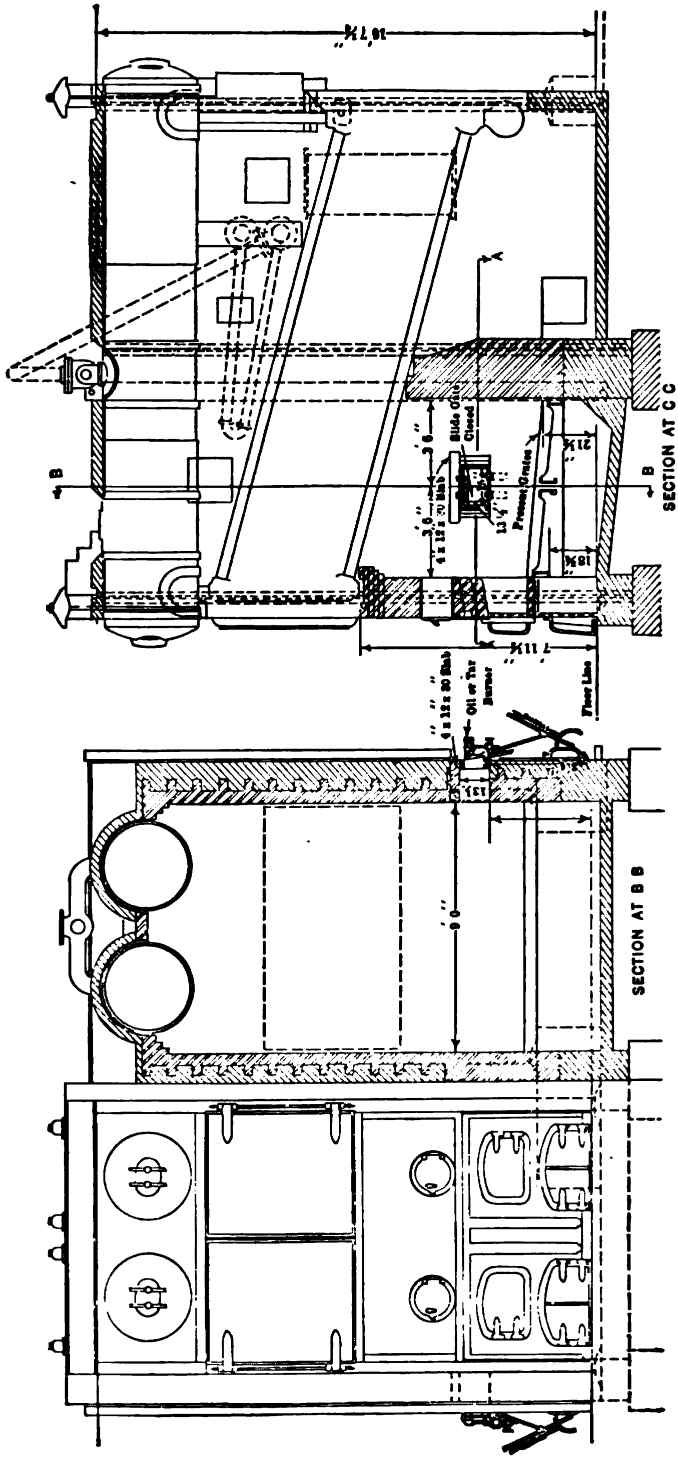


FIG. 32.—Hand-fired boiler equipped for the burning of oil in combination with coal.

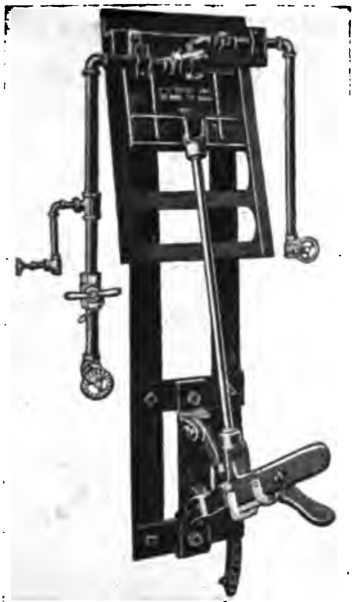


Fig. 33.—Fluid-injecting apparatus.

Fig. 34.—(We are indebted to Jos. W. Hays Corporation, Michigan City, Ind. for cut of this CO_2 recorder.)

Fig. 35.—(We are indebted to the General Electric Company, New York City for cut of this steam flow meter.)

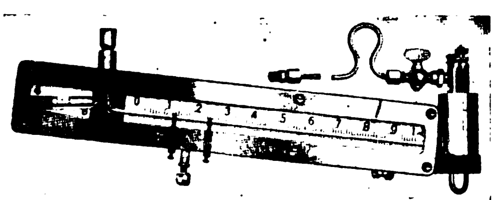


Fig. 36.—(We are indebted to Mr. Lewis M. Ellison of Chicago, Ill., for the above cut and description of gage.)

With the differential draft gage an increase in air supply from any source moves the liquid in but one direction, forward, and a decrease in air supply has the opposite effect. Therefore, the indications of this gage are a sure guide to the amount of air passing through the setting regardless of the position of the damper or ash-pit doors.

To indicate the varying air supply, the outside cocks are open and the middle cock is closed as shown, the liquid operating between the air-supply pointers as indicated.

The flue draft is indicated by opening the outside cock and closing the other two.

In power plants in water-tube boilers using atomizing burners, it requires 147 gallons of oil to represent a long ton of coal.

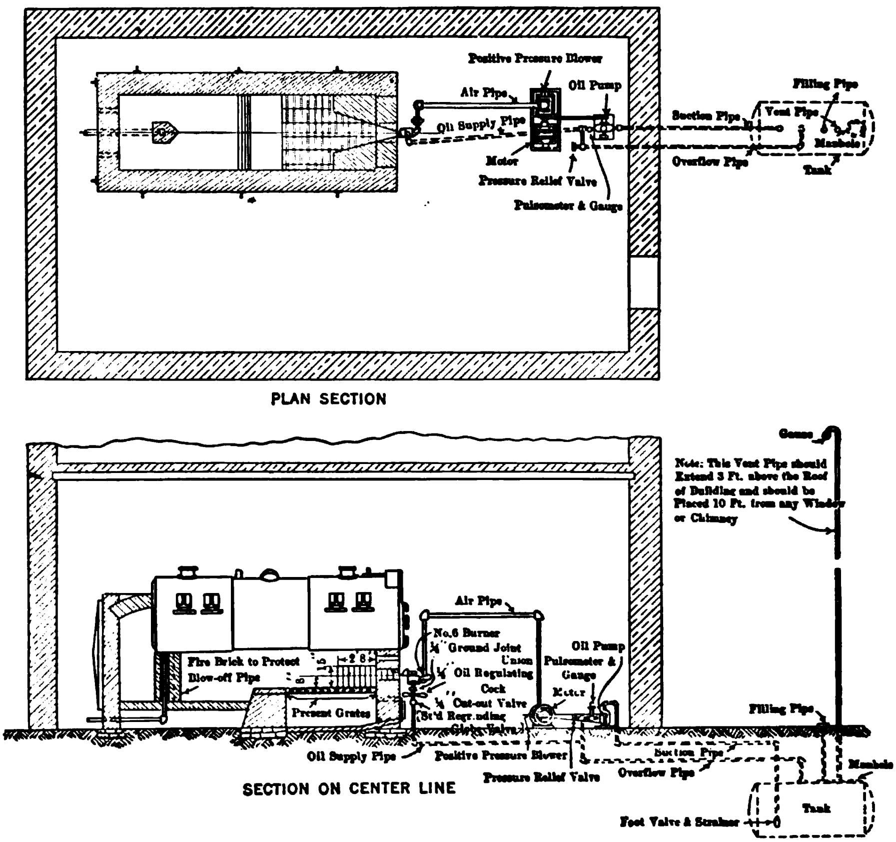


Fig. 37.—Complete hot water or low-pressure steam boiler equipment.

The equivalent of 1000 cubic feet of blast furnace gas of 90 B.t.u. per cubic foot is 0.42 gallon of oil. This gas is used in this country in boilers and also in large furnaces, but requires coal tar or oil to aid in keeping up the required horse-power of the boilers or in furnishing the temperature required for the heating furnaces. Oil and coal tar are excellent fuels which can readily be used to operate in conjunction with the blast furnace gas in boilers or in large furnace practice.

Usually 10 gallons of coal tar are made from every ton of coal coked in by-product coke ovens. This tar has a calorific value of 162,000 B.t.u. per gallon and weighs 10 pounds per gallon.

When dry, 3½ barrels of oil (42 gallons per barrel) are equivalent to 5000 pounds hickory or 4550 pounds white oak.

The equivalent of 1000 cubic feet of by-product coke oven gas, having a calorific value of 440 B.t.u. per cubic foot is 2¼ gallons of oil.

Of course it should be remembered that the coal referred to has a calorific value of 14,000 B.t.u. per pound and is figured by the long ton (2240 pounds). The oil referred to has a calorific value of 19,000 B.t.u. per pound and weighs 7½ pounds per gallon.

Do not try to compare the calorific value of fuels without knowing the kind of service demanded of them.

Where there is no compressed air or steam with which to atomize the oil and distribute the heat, it is necessary to provide some means for atomizing the oil and circulating it in order to meet the underwriters' requirements. Fig. 37 shows the manner of applying oil to a hot water boiler or low pressure steam boiler. The same equipment can also be used in hot-air furnaces.

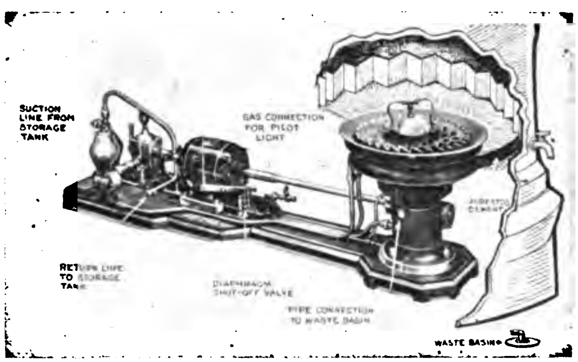


Fig. 38.—Automatic Aetna burner.

The tank is placed underground and 5 feet from any building, in accordance with the underwriters' requirements or with the ordinances of the city where the oil installation is to be made. A small electric motor drives a small positive pressure blower, the blower furnishing air with which to atomize the oil; and connected on a shaft between the motor and positive pressure blower is a pulley which drives a small pump. This is a very safe system, for if an accident occurs to the motor the entire plant shuts down.

There are several different forms of these oil installations for the purpose above mentioned. Some are mechanical in form, such as the system hereinafter described.

This rotary burner (Fig. 38) is operated by an electric motor.[1] The motor also operates an oil pump which furnishes the supply of oil to the burner. The system is provided with the most modern attachments, making it safe, sane, and automatic; it is exceedingly simple to operate, durable in construction, noiseless and clean. It burns fuel oil, distillates, or kerosene and can be attached to a hot-water boiler or hot-air heater within three hours after the oil tank and piping have been installed.

Oil Equipment for Sugar Industry

In Fig. 39, 39*a* and 39*b* one burner is located on the Dutch-oven end and is used simply to heat the oven before charging in the bagasse, after which this burner is swung

[1] (The writer is indebted to Mr. John Scheminger, Jr., President of the Aetna Automatic Oil-Burner Inc., Providence, R. I., for the cut and description of this burner.)

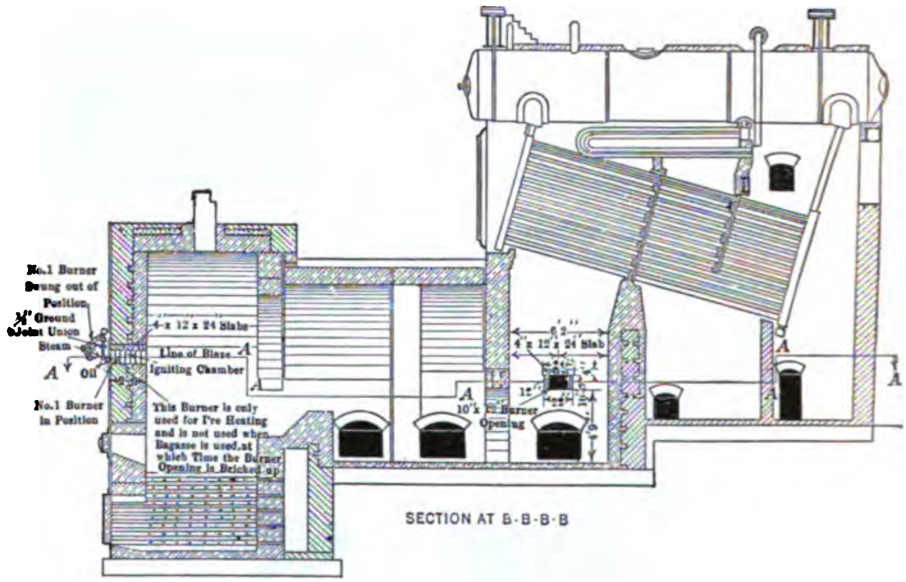


Fig. 39.—Combination oil and bagasse equipment for boiler in sugar centrals.

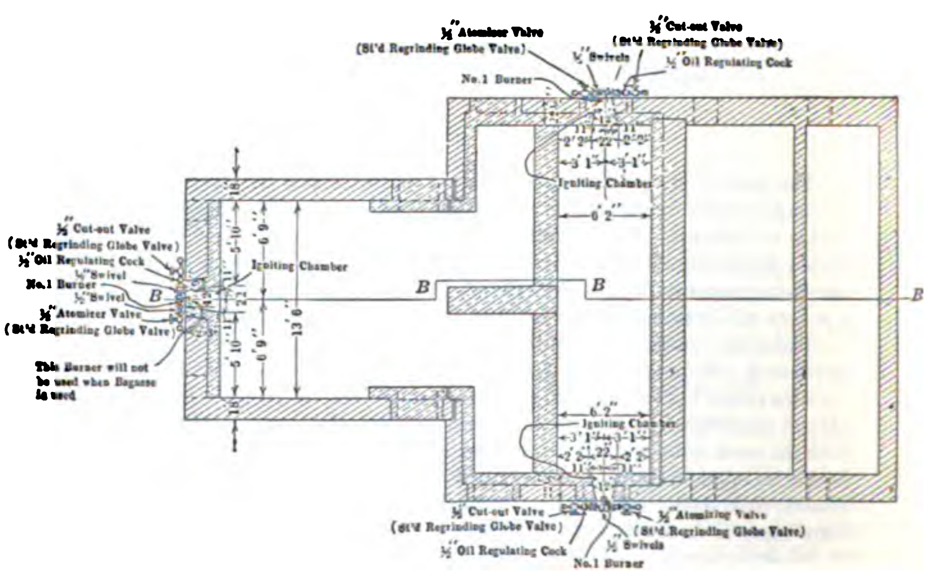


Fig. 39a.—Combination oil and bagasse equipment for boiler in sugar centrals.

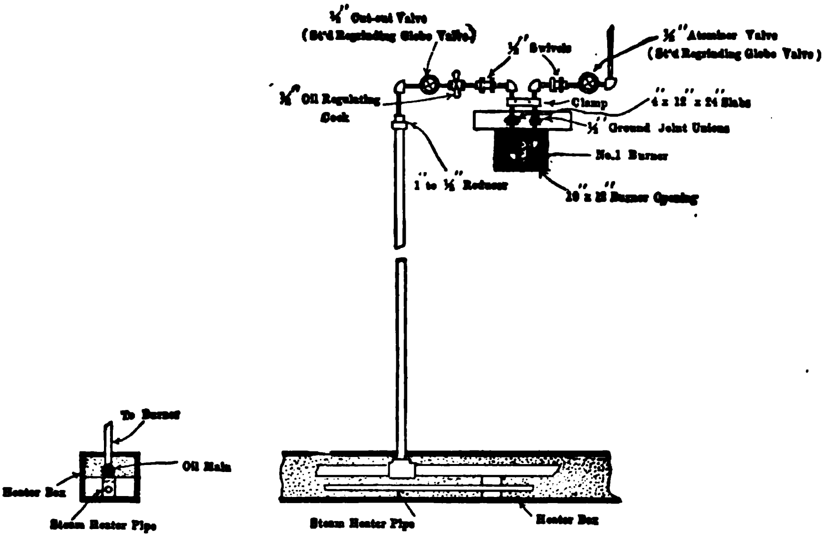


FIG. 39b.—Swivel-joint burner piping. Also heater box required for burning heavy oil.

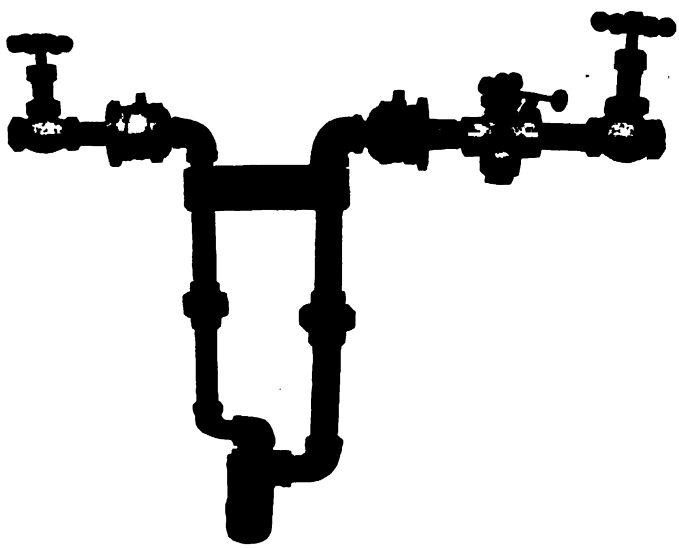


FIG. 40.—Oil and tar burner mounted with swivel-joints.

out of position. This burner is not used when the bagasse is burned and the opening for it is therefore closed. The other burners should be placed in the side wall immediately under the elements of the boiler, sufficiently high so that the slag from the bagasse will not interfere with the path of the flame of the oil burner.

Swivel-joint burners (Fig. 40) may be used for this class of service but better and more economical results can be obtained by using the fluid-injecting apparatus shown in Fig. 33.

It ordinarily requires about 3 gallons of oil per ton of bagasse burned to carry a normal load upon the boiler. Oil is an excellent fuel for this purpose.

Oil Equipment for Marine Boilers

In the equipment of marine boilers it is necessary to remove the grates and use a manhole door constructed in the manner shown in Fig. 41.

Note the manner of constructing the ignition chamber. It is always necessary to protect the rear lap seam of the corrugated furnace with firebrick. This can be done very simply by putting one row of arch brick around the lap seam.

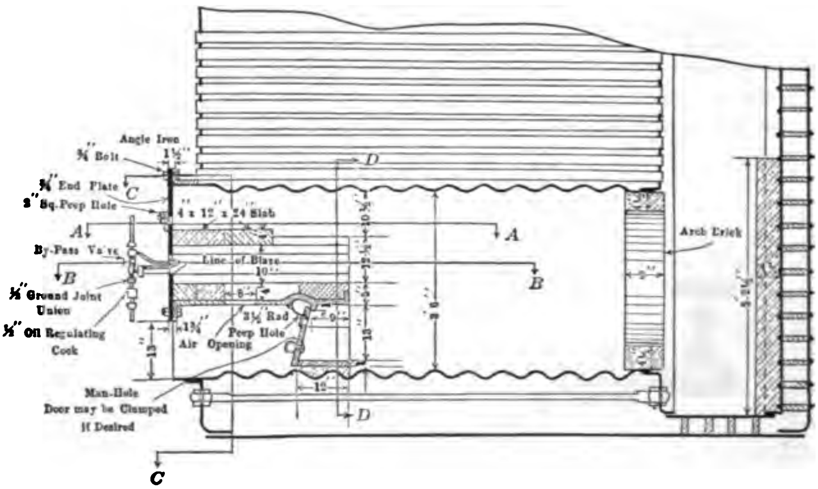


Fig. 41.—Marine boiler equipment.

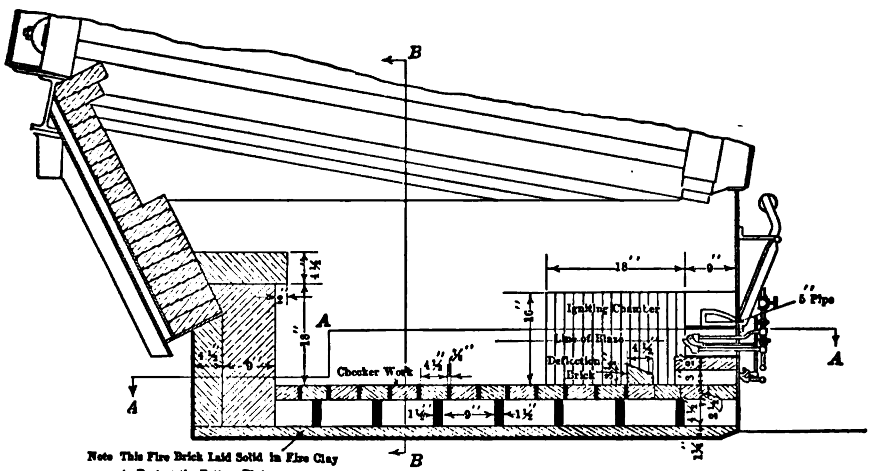
In wet-back Scotch marine boilers, it is necessary to use a row of firebrick in the manner shown, in Fig. 42 to protect the shell and staybolts. Note that the elements of this boiler are very low.

Fig. 43.—Note that the elements are quite a distance from the checker work or floor of the furnace.

In tugboat service, using atomizing burners, it requires 147 gallons of oil to represent a long ton of coal. In marine service, using mechanical burners, it requires 180 gallons of oil to represent a long ton of coal. Therefore, oil is more attractive as a fuel for tugboat service than it is for ocean-going vessels. In numerous tests, it has been found that two oil-fired tugboats will take the place of three tugs of the same size and power, having all other conditions the same and using coal as fuel.

The coal referred to in comparing these two fuels has a calorific value of 14,000 B t.u. per pound and is figured by the long ton (2240 pounds), while the oil has a calorific value of 19,000 B.t.u. per pound and weighs 7½ pounds per gallon.

In ocean-going vessels plying between the ports of New York, Havre, Liverpool, Hamburg, etc., the most modern practice is to use mechanical burners, description of which is given below. This is because the use of this type of burner prevents the excessive use of fresh water which would be required with the atomizing type of burner.



SECTION ON CENTER LINE

FIG. 42.—Babcock & Wilcox water-tube boiler—marine type.

The apparatus shown in Fig. 44 is of the so-called mechanical atomizing type, in which the spray is produced by oil pressure only, without the use of an atomizing medium such as compressed air or steam. In this type of atomizer, the oil is given a rapidly whirling motion inside the tip and leaves the orifice of the tip as a conical spray of finely divided particles, the spraying effect being produced by centrifugal force.

Fig 45. shows a complete Babcock & Wilcox mechanical oil-burning unit, the important elements of which can be briefly described as follows:

1 is the cast-iron bladed cone; 2 is the main register casting, which is bolted directly to the boiler front plate, thus holding the cone (1) in place. The main register casting is fitted with four automatic air doors (3) by the use of which the quantity of air supplied to the burner may be regulated at will and shut off entirely if desired. These doors are so designed that they will close automatically in case of a flare-back in the furnace or the bursting of a boiler tube, thus protecting the fireman who may be standing in front of the boiler.

To the front of the register casting is fastened a cover-plate (4) fastened with studs to the main register casting and holding in place the radiation guard (5) and the spider casting (6). This spider has four cams which control the operation of the automatic air doors (3). Fastened to the spider (6) and passing through a slot in the cover-plate (4) is a handle (7) to facilitate the operation of the spider. By moving this lever to the extreme right the air doors are all closed and by moving it to the left the doors are gradually opened.

Passing through the center opening in the cover plate (4) is a distance piece (8) to the room end of which is fastened a quick-detachable yoke and coupling (10 and 9). To the other end of this distance piece is fastened a cast-iron conical shaped impeller plate (11). Passing through the center of the distance piece (8) is a mechanical atomizer (13), this atomizer being held in place and connected to the fuel-oil supply line

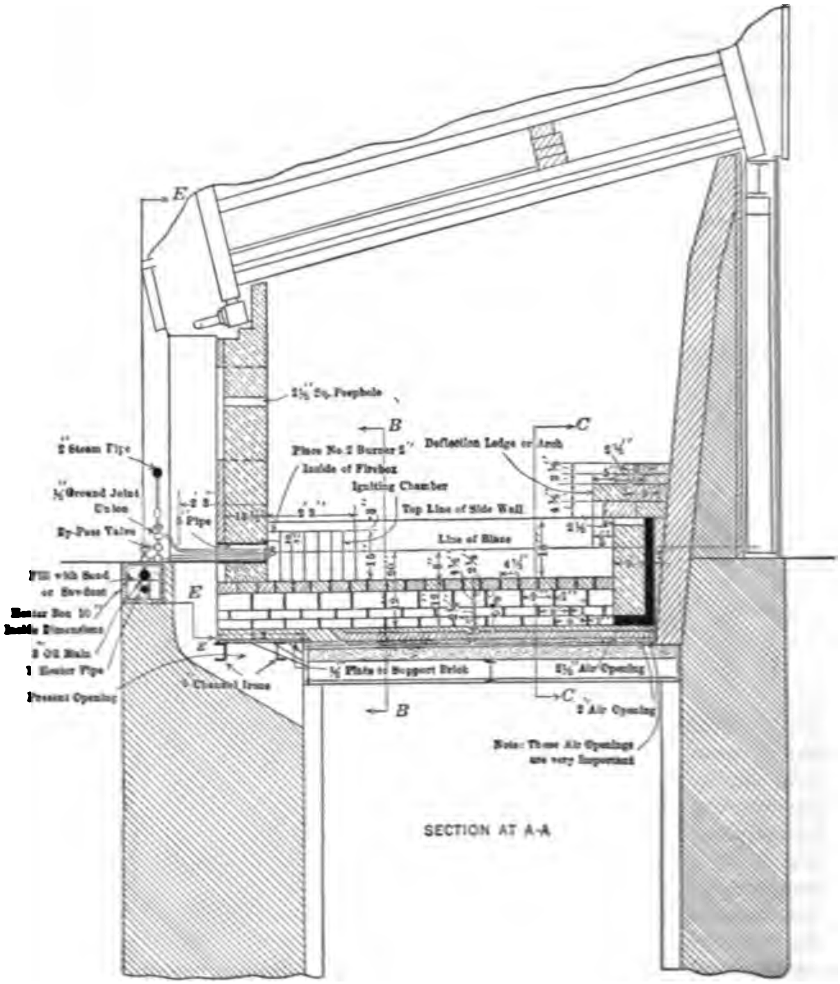


FIG. 43.—Babcock & Wilcox water-tube boiler, marine type—modern.

FIG. 44.—Babcock & Wilcox mechanical atomizer.

through the quick-detachable coupling and yoke (9 and 10), thus making the atomizer (13), the distance piece (8) and the center impeller (11), a rigid unit when in operation. The distance piece is so designed that it may be moved along its axis, thus moving the center impeller (11) in and out of the bladed cone (1) and thus decreasing or enlarging at will the clear area for the passage of air around the outside of the center impeller (11). Thus by pushing the center impeller in toward the furnace this clear area is considerably reduced and by pulling it out to the position in which it is shown in Fig. 47, the maximum clear area will be obtained. By means of a set screw (12), the center impeller (11), together with the distance piece and atomizer, may be fastened in any desired position.

To adjust the distance between the tip of the atomizer (13) and the small opening in the center of the cast-iron impeller (11), the headless set screw (14) is unscrewed, and while the distance piece (8) is held with the set screw (12) the coupling may be rotated on the distance piece to any position desired. The distance between the tip of the atomizer and the small opening in the center of the cast-iron impeller should be maintained at approximately ¼ of an inch, and when the coupling (9) is moved up on the distance piece (8) sufficiently to bring this condition about, the headless set screw (14) should be driven home. If this adjustment (to bring the tip of the atomizer within ¼ of an inch of the opening in the center of the cast-iron impeller) has once been made (usually at the time the apparatus is first set up), it should never have to be repeated. *It is important that all burners have this adjustment made before lighting up.*

Operation of system.—In starting up a boiler with this style of apparatus first be sure that all of the burner atomizers are thoroughly clean and that there will be no danger of poor atomization because of plugged strainers or because of chips or pieces

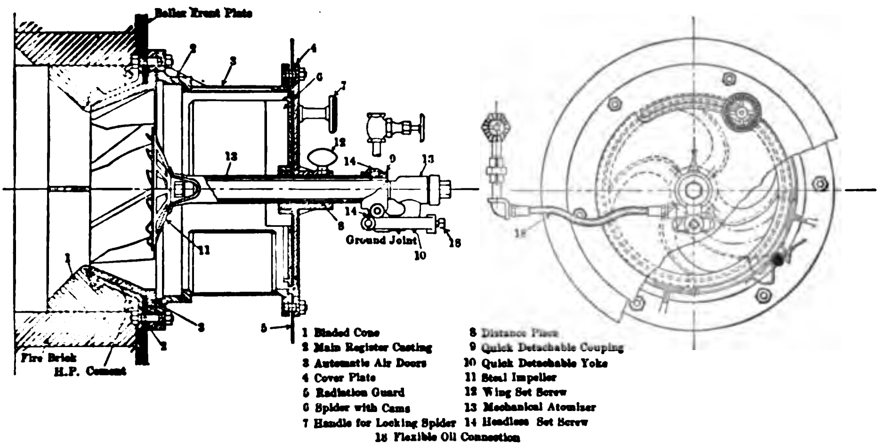


Fig 45.

of waste in the oil passages of the atomizer. Also be sure that all valves leading to the different burners are closed. If reciprocating oil pumps are used and an air cylinder is provided in the oil line, have the necessary connections made so that this cylinder can be charged with air after the oil is started through the system. It is *very necessary* that the fluctuations in pressure of the oil from the pump be eliminated by the air cylinder before the first burner is lighted.

After taking these essential precautions, start circulating the oil through the system

(without lighting any of the burners) until the piping is thoroughly warm and the oil has reached a temperature which will make it possible to atomize it in a satisfactory way.

Care of atomizer.—One of the most important points in connection with the satisfactory operation of burners is the inspection and care of the atomizer. It is very essential when burning oil by mechanical atomization that the atomizer be kept thoroughly clean at all times, as a slight plugging in any of the oil passages causes poor atomization at the tip, black streams of oil and poor combustion. When an atomizer in operation does not give a perfectly uniform cone of oil spray it should be taken out and replaced by a spare atomizer and then thoroughly cleaned and placed on the spare atomizer rack. The operator should, therefore, be careful to observe the tips of the atomizers (through the peepholes provided in the top air-door of the register) at frequent intervals, to observe the appearance of the oil spray coming from them, as even a very complete system of strainers does not entirely prevent the plugging of atomizers.

In cleaning an atomizer, first unscrew and remove the steel tip, which in turn brings the small slotted sprayer plate with it. This sprayer plate should be washed in gasoline or kerosene and carefully examined for the cause of the plugging, as experience has shown that most plugging occurs in one of the four channels of this plate.

If the cause of the plugging is discovered in the sprayer plate it will be unnecessary tc remove the nozzle (to which the tip is secured), but if nothing has been found in the passages of the sprayer plates, the nozzle should be unscrewed from the barrel of the atomizer and thoroughly examined and cleaned. These three pieces should then be replaced on the burner barrel in their respective positions. If the atomizer has been in operation for any length of time (twelve or fifteen hours) the strainer in the body of the burner will undoubtedly need cleaning. To do this, the brass cap on the back of the body should be unscrewed, the strainer removed and a spare strainer slipped in its place, the dirty strainer being cleaned with kerosene at the operator's convenience. After the brass cap has been replaced, the atomizer may be placed in the spare rack ready to be used at any time.

Cause and elimination of carbon in furnace.—Should any carbon " build up " on the cast-iron center impeller, or the brickwork around the burner opening, or on the furnace side walls or floor, it may be removed in two ways:

1st. By shutting off the burner which is " building up " the carbon and leaving it shut off until the radiant heat from the other burners and hot brickwork burn up the carbon. While this is being done the air doors in the register of the burner that is shut off should be left open a small distance to supply air for burning up this carbon.

2d. By cutting the carbon away with a rod or bar of iron (flattened to a chisel edge at one end) inserted through the wide-open air doors of the register.

Due to the wear and tear on the brickwork, castings, etc., by the second method, it is decidedly preferable to use the first method if the power requirements will allow a burner to be shut off long enough to burn up the carbon. Before the burner is again lighted up after burning or cleaning off the carbon, a careful examination should have been made to determine the cause of the formation of the carbon and this cause eliminated. The formation of the carbon may be due to one or all of a number of causes, as, for example, oil too cold for proper atomization; one air door of the register stuck in the closed position, leaving only three open; or all four doors in the register too nearly closed. Also the furnace brickwork may be too cold, due to the use of excess air.

(The Babcock & Wilcox Company, New York, N. Y., has kindly furnished the above description and cuts (Figs. 45 and 46) of their mechanical oil-burning system.)

Oil Equipment for Locomotives

Oil is an excellent fuel for use in locomotives of all sizes, for with it smoke can be eliminated. Again, when the locomotive is changed from coal fuel to oil, the tonnage is increased 15 per cent. This is because the full pressure of steam can be maintained upon the boiler while pulling the tonnage on a level track or up any ordinary grade.

Only one burner is used in large locomotives. (See Figs. 47 and 48.) In the equipment of locomotives it is very important that the air opening in the inverted arch be of proper proportions for the size and service of the locomotive. If this opening is too

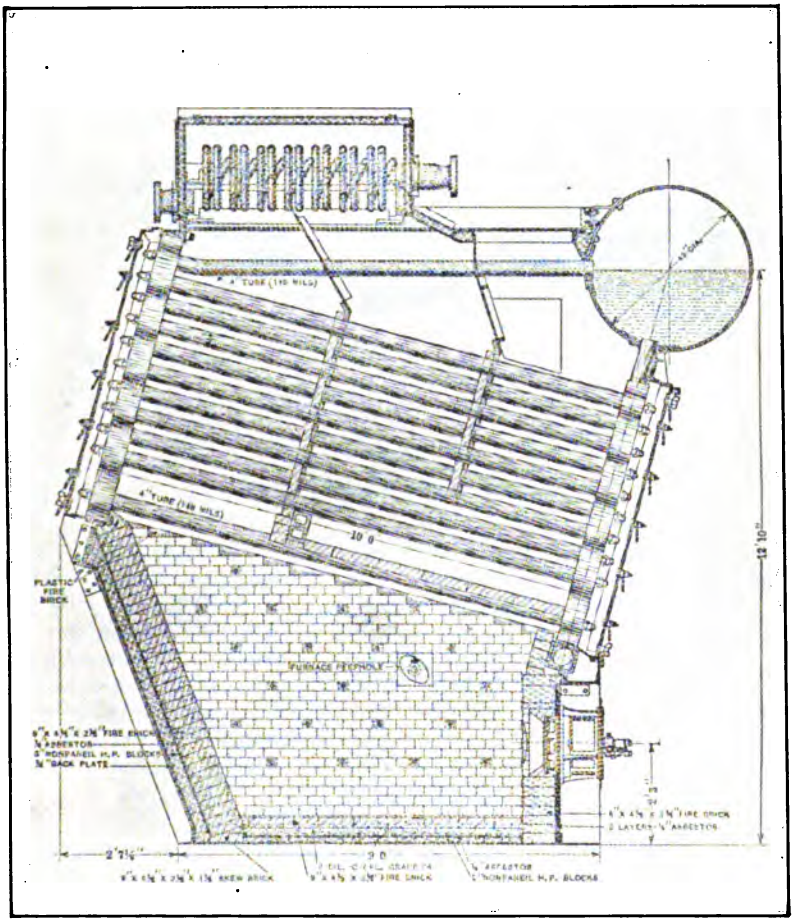


Fig. 46.—Babcock & Wilcox marine boiler fitted for oil fuel.

large, it means that a superfluous amount of air will pass into the firebox, resulting in loss of fuel; and if too small, the locomotive cannot pull its tonnage because it cannot get sufficient oxygen for combustion. The equipment of locomotives is therefore an engineering feat, and before a man can equip them successfully, he must have had the practical experience of burning oil in locomotives.

For small locomotives (Fig. 49*b*) the author always recommends two burners—one a

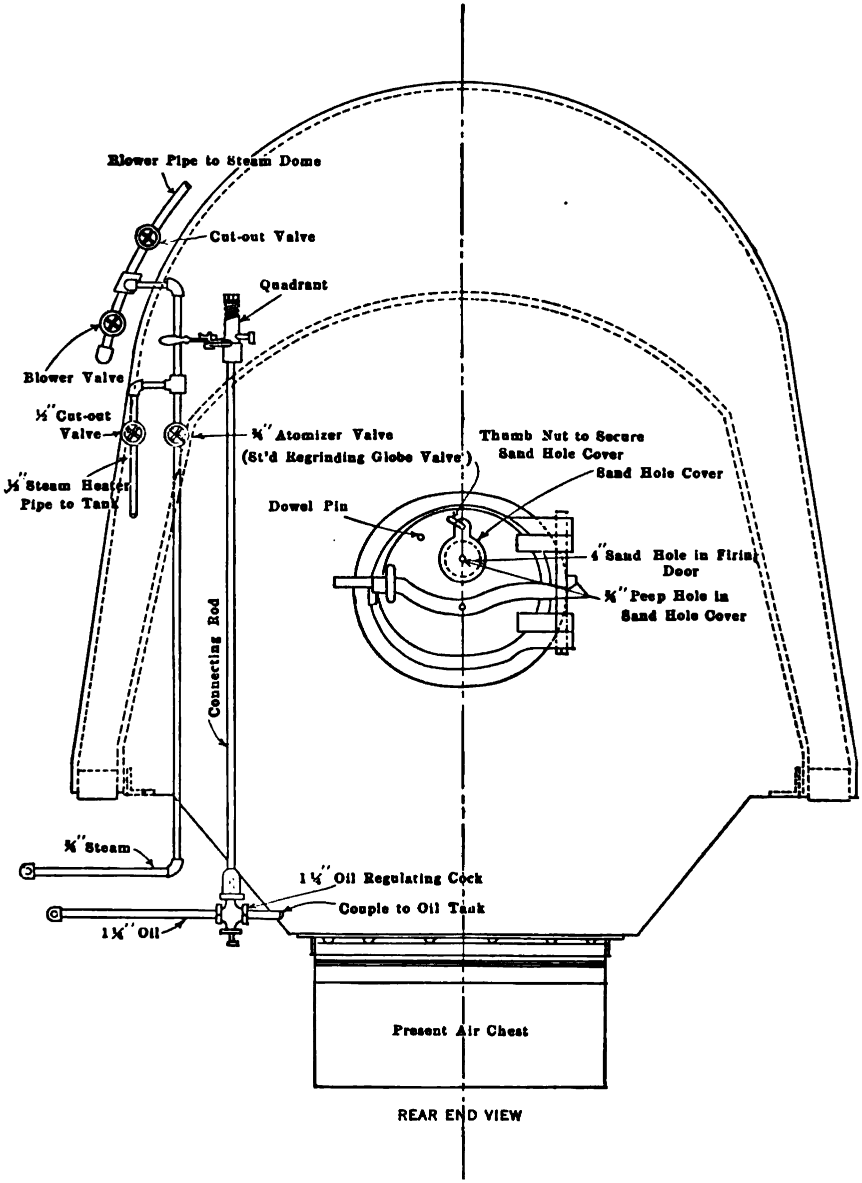


Fig. 47.—Large locomotive equipment. View showing piping and location of oil regulating cock, quadrant, etc.

small burner to serve as a pilot light. This burner is operated at all times, its function being to keep the pressure of steam in the boiler at just below its popping-off point. The larger or service burner is operated only when the locomotive is called into service. By the use of the pilot burner the required steam is made available for immediate service at all times. The brickwork is also kept hot, and when the larger burner is ready for operation, the flame from the pilot burner instantly ignites the atomized fuel fed by the larger burner.

The author always insists on this duplex system in small locomotives, or for switching engines, etc., where the service is intermittent.

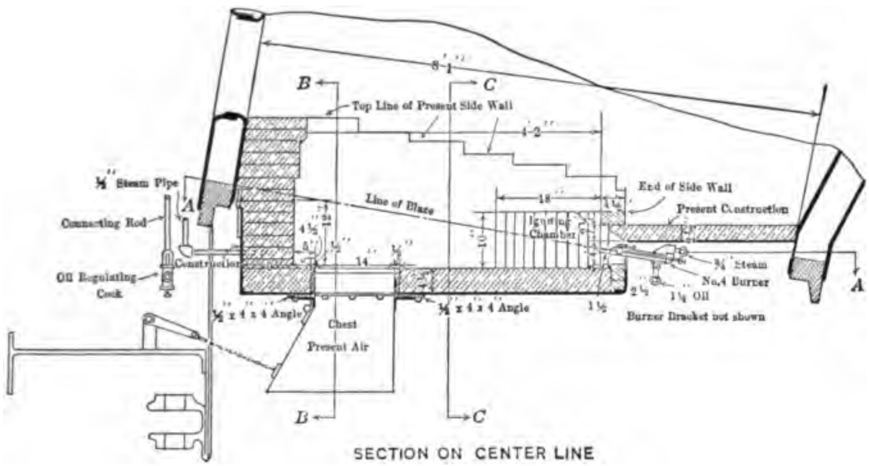


Fig. 48.—Large locomotive equipment.

The oil tanks (Figs. 50 and 50*a*) vary in size and form according to the size of the coal space in the tender of the locomotive. Note that means are provided for heating the oil with a ½-inch direct live-steam pipe. Years ago it was the practice to provide heater coils in the interior of the tank, but this practice has long since been stopped, for it puts a locomotive out of service for possibly three or four hours.

In locomotive service, using atomizing burners, it requires 180 gallons of oil (calorific value 19,000 B.t.u. per pound, weight 7½ pounds per gallon) to represent a long ton (2240 pounds) of coal, the coal having a calorific value of 14,000 B.t.u. per pound.

Oil as Fuel in Forge Shop Practice

In all modern plants the first consideration should be space; the second, the location of different departments so that the metal will pass from the stock room into the forge shop, from the forge shop into the heat-treating department, then to the store room. There should be no waste movements and no imperfect operations.

The furnaces should be of ample capacity to heat the amount of metal required for the forging machine, steam hammer or drop; and, in order to turn out the maximum output, they should be portable in construction so that when an arch, jamb, or other part of a furnace needs to be repaired, the night shift can, by the aid of the cranes which are ordinarily used to supply the furnaces with metal and transfer the metal to any place in the works desired, lift up and carry the furnace into the masons' room. As soon as this is done, a furnace which has already been relined is taken from the masons' room

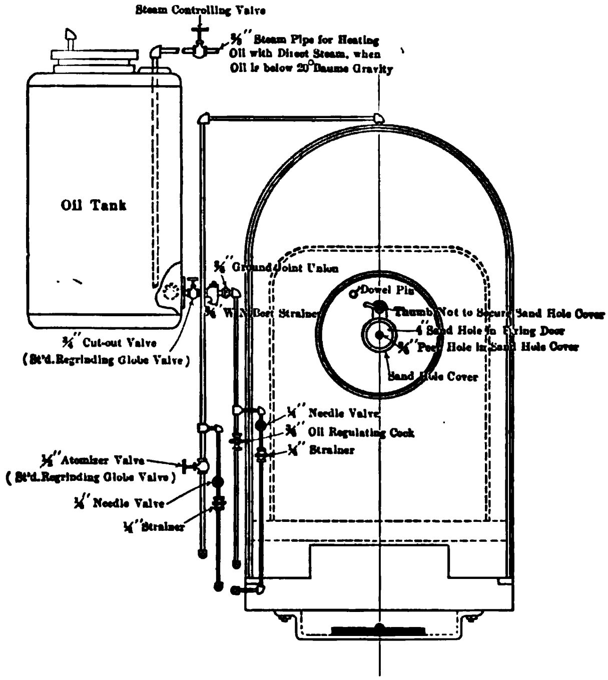


Fig. 49.—Equipment of a small locomotive such as is often used around large plants.

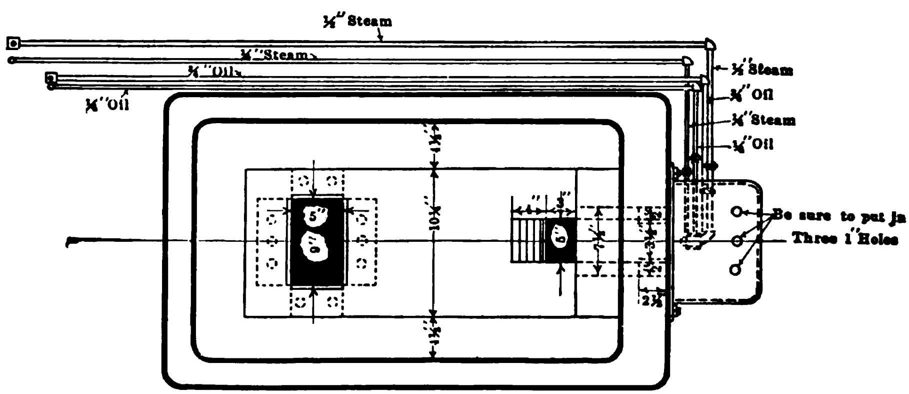


Fig. 49a.—Plan view—small locomotive equipment.

and placed in the position from which the other furnace was removed. The oil burner is then started in order that the furnace may be sufficiently heated for the operator in the morning.

The small drop-forging furnaces ordinarily used with board drops should also be portable in construction and provided with two openings, so that metal may be charged in one of the openings and brought to heat while the former charge is being drawn from the other opening in the furnace. These furnaces are known as twin-type furnaces, and are illustrated in Figs. 56 and *56a*.

The heat-treating furnaces should also be portable in order that they too may be relined when demands require, just the same as the large forging or drop-forge furnaces. They should be placed in battery so that no unnecessary steps are required by the operators. The use of pyrometers is always recommended for the value of steel depends upon the care with which it is heat-treated.

The furnaces are of modern construction and without stacks. The men are satisfied for they are employed continuously, and the officials are also satisfied, for the maximum output can be produced at all times, since there are no idle furnaces.

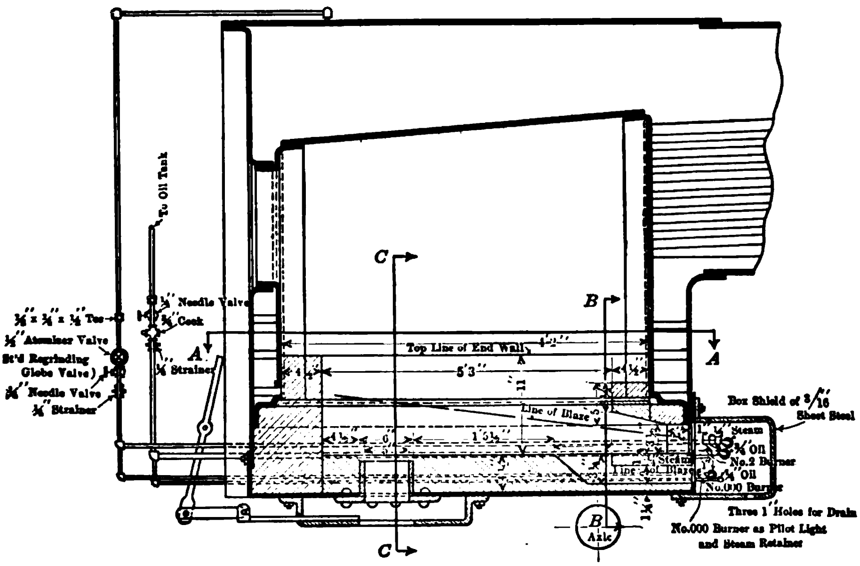


FIG. 49*b*.—Small locomotive equipped with pilot burner as well as the usual oil burner.

It is very important that the building should not be constructed until the proportions of the furnaces required are known. In other words, never build a building until the size of the furnaces required for maximum output is known.

The heat-treating furnaces should be of semi-muffle type, with graduated heat ports so that an even distribution of heat can be attained and maintained throughout the entire charging space of the furnace.

As some oils contain considerable sulphur, it is necessary to use canopies over the vents of the furnaces in order to carry away the sulphurous fumes.

From Fig. 57 it will be noticed that two pumps are provided so that one can be held in reserve in case of an emergency. The pipes are so located as to insure the perfect circulation of the oil throughout the entire plant.

Of course, the tensile strength of the metal is increased by heat-treating, and the

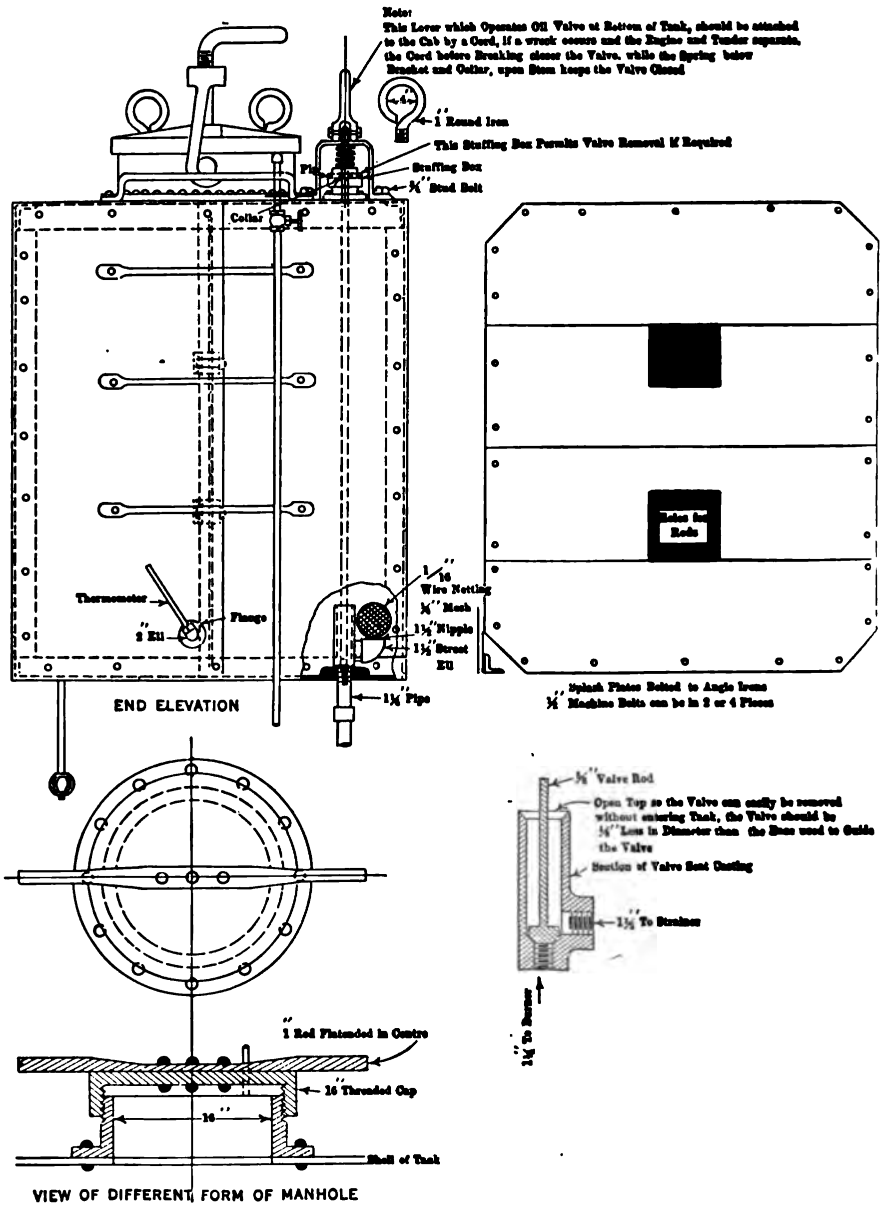


FIG. 50.—Modern oil tank used for carrying oil in the tender of locomotive.

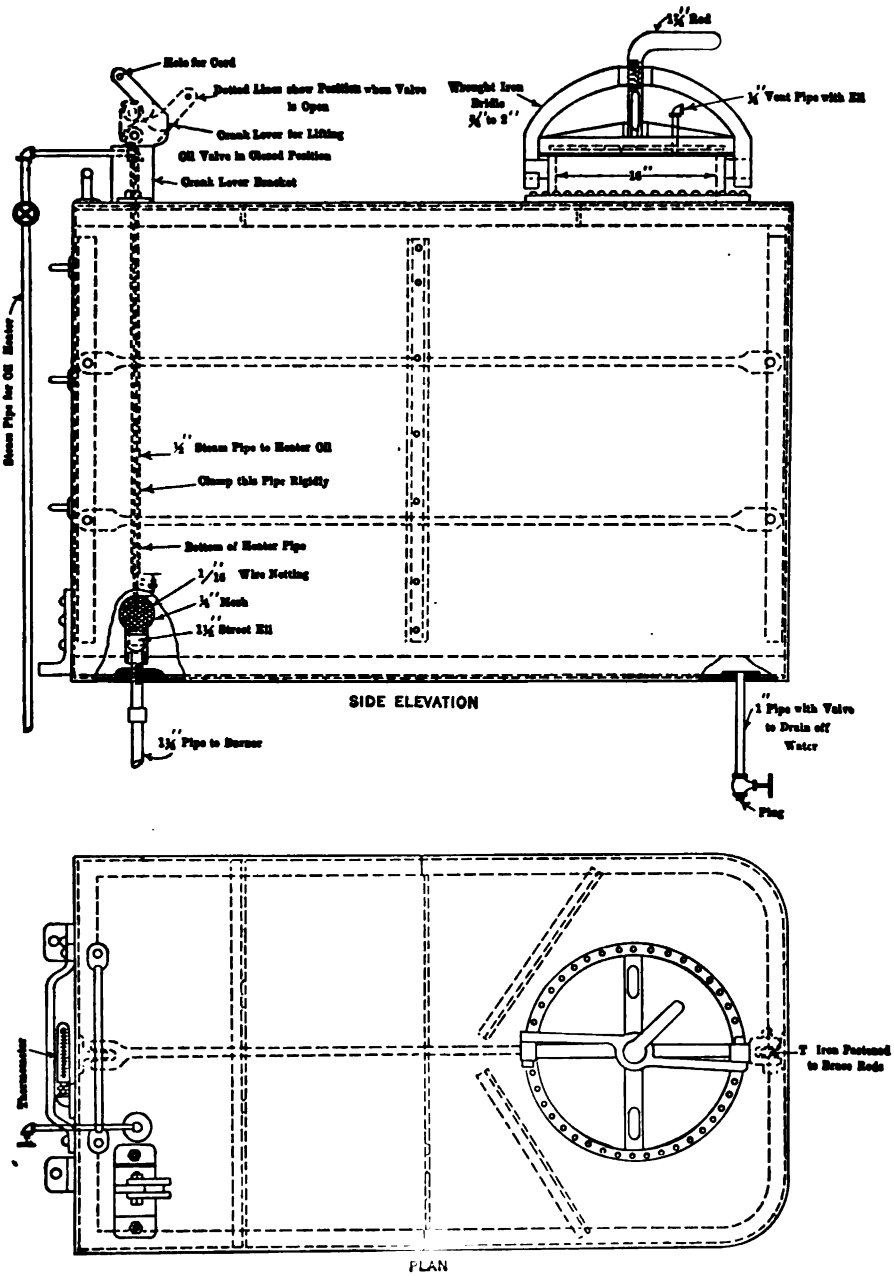


Fig. 50a.—Modern oil tank used for carrying oil in the tender of locomotive.

Fig. 51.—Locomotive oil burner.

Fig. 52.—Pilot light burner.

Fig. 53.—Locomotive oil regulating cock.

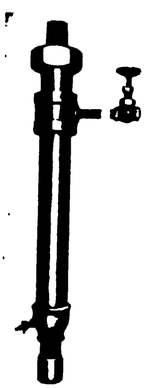


Fig. 54.—Locomotive oil heater.

Fig. 55.—Fireman's regulating quadrant.

metallurgist must advise the furnace operator as to the temperature required, while he in turn maintains the temperature specified by the metallurgist.

The superintendent who copies the furnace construction and methods of other companies cannot lead. The construction of the furnaces and the method of operating learned in another plant may be absolutely impractical in his plant, and the result is that his imitation ends in a miserable failure. It is all very well to investigate methods, but it is not always wise to copy them. There are so many things that enter into their practical use that one must be very guarded in striving to emulate the exact practice of another works.

Billet heating furnaces are made up in various forms for various services. Sometimes the charge is withdrawn from side doors, while at other times it is automatically dropped down from the end of the furnace upon carriers which carry the ingots or billets into the mill.

At times these continuous furnaces are connected with stacks and waste-heat boilers, while at other times they are vented from ports at the charging end of the furnace. Only one burner should be used in this type of furnace.

Continuous furnaces are made in two types, the declined-hearth and inclined-hearth types. The declined-hearth type (Fig. 58) is more popular.

There is no stack upon the portable furnace (Fig. 59) and the charging space is 5 feet wide by 14 feet long. It will be noticed that the furnace is built upon steel channels so that it can be removed as hereinbefore described.

Fig. 60 shows the method by which the volume air is preheated by the superheater placed immediately above the vents of the furnace. The air is preheated before being delivered to the furnace through the nozzle under the burner.

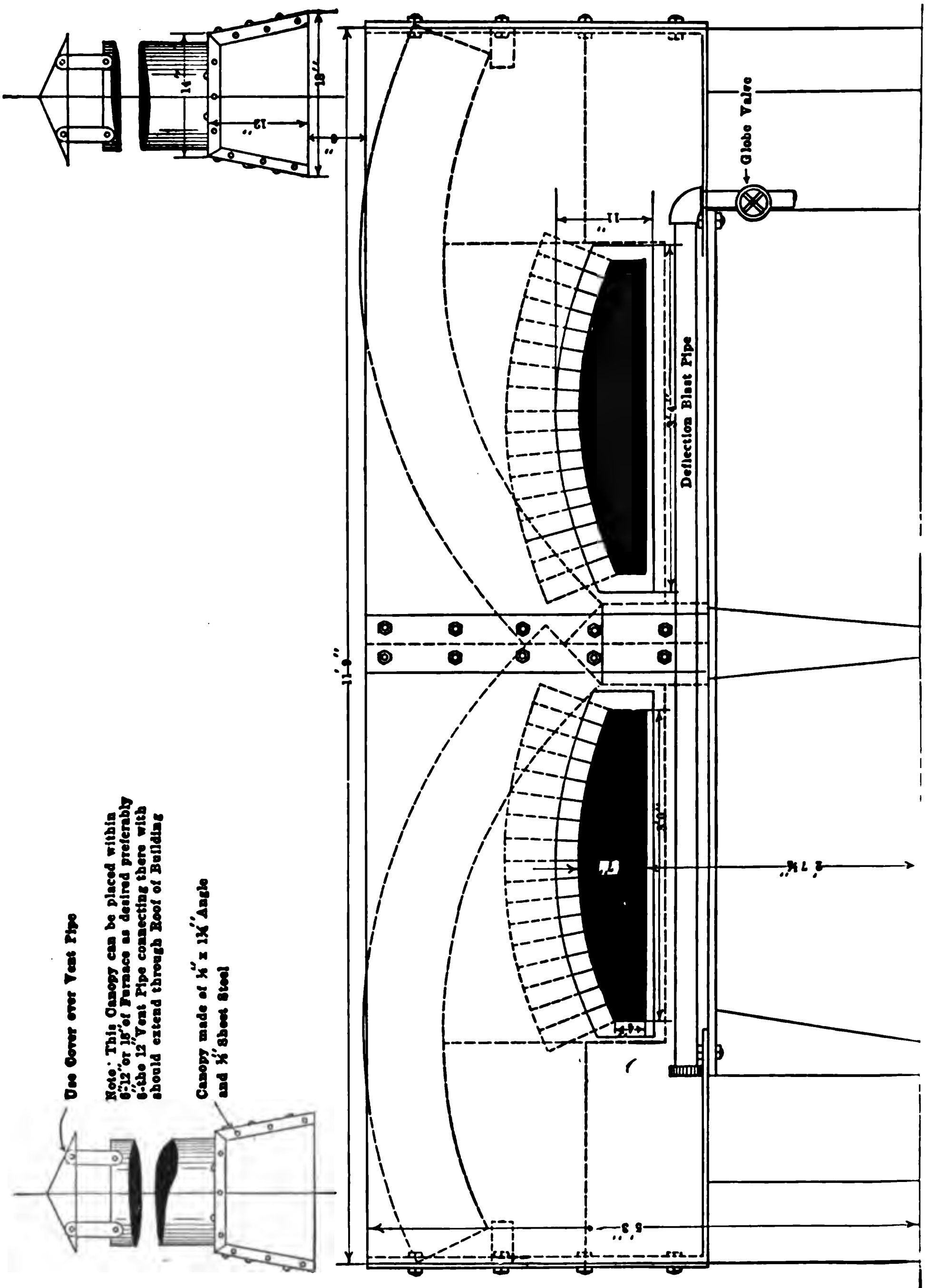
Fig. 61 shows a modern type of billet-heating furnace in which oil can be used in combination with natural gas, or either fuel can be burned exclusively. An ingot 30 inches in diameter can be charged into this furnace and heated to a forging temperature in two and one-quarter hours, while in a coal-fired furnace this operation would require twenty hours.

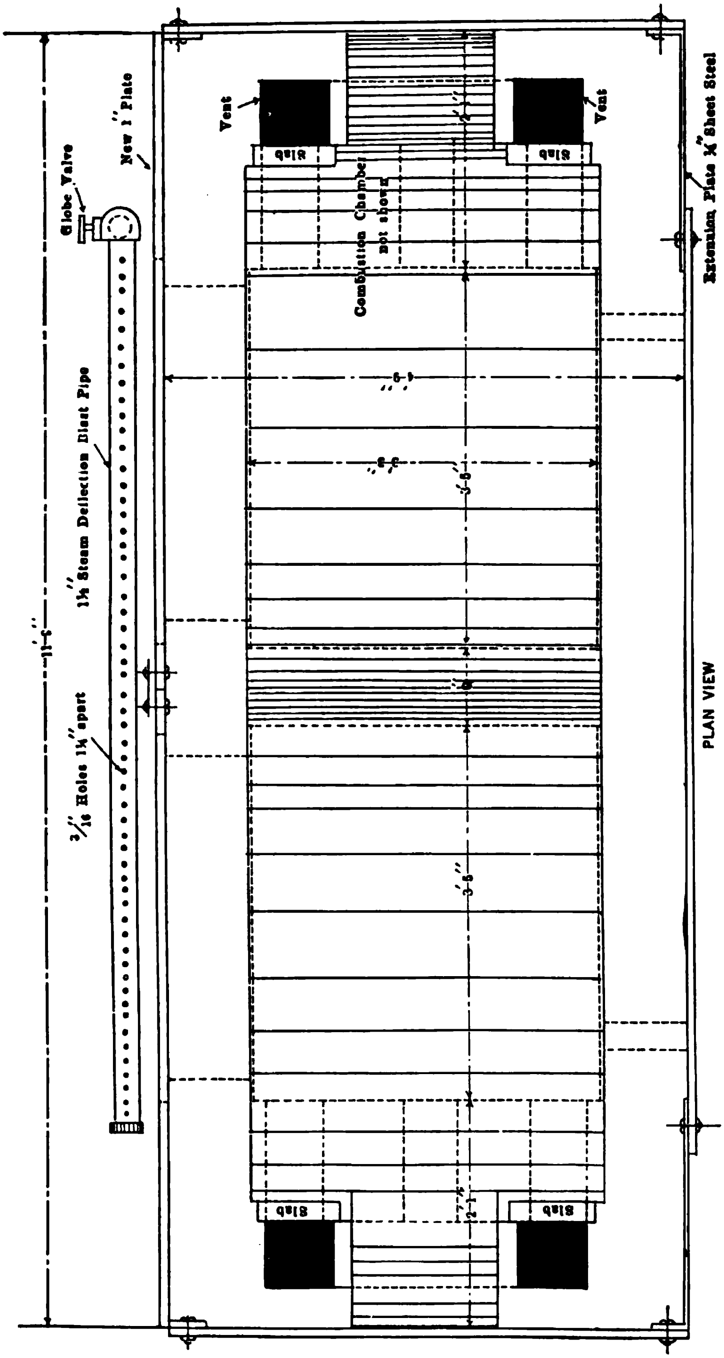
Oil is such a superior fuel in forge practice that if Mr. A is using oil as fuel and Mr. B coal, in a short time Mr. A will put Mr. B out of business, simply because he can turn out double the quantity of forgings, the metal will be of superior quality and will be freer from scale. While Mr. B may have the same commercial and mechanical ability as Mr. A he cannot compete with him. If the metal is to be heat-treated, certainly Mr. A has every advantage, owing to the superior quality of metal he can produce. Again too, Mr. A's dies will last much longer, for the life of the die is always increased by using oil as fuel. Oil produces a much softer metal since it gives a penetrating heat, while coal, coke or gas make only an abrasive heat. This is very noticeable in changing a furnace from coal fuel to oil.

In the construction of furnaces, it is always important to use the best non-expanding fire-brick procurable that will withstand the temperature the work requires, remembering that it costs just as much to build or reline a furnace with poor brick as with good brick, and some firebrick are not worth putting in at all.

Modern heat deflectors should be provided to deflect the heat from the furnace operator. This should be done in order to prevent the workman from becoming overheated and to enable him to obtain the maximum output with minimum fatigue.

Every furnace should be of the proportions required for the maximum output. It should be modern in every detail and should be so constructed that the upkeep of the furnaces is reduced to the minimum. Construction along scientific lines is absolutely essential in order to get the maximum output and maintain the required temperature and an even distribution of heat. These points are essential and must always be considered by the engineer designing the furnaces.


Globe Valve
Deflection Blast Pipe
Use Cover over Vent Pipe
Note: This Canopy can be placed within 6"-12" or 18" of Furnace as desired preferably 6-the 12" Vent Pipe connecting there with should extend through Roof of Building
Canopy made of ¼" x 1¼" Angle and ⅛" Sheet Steel



PLAN VIEW

FIG. 56a.—Twin type forging furnace.

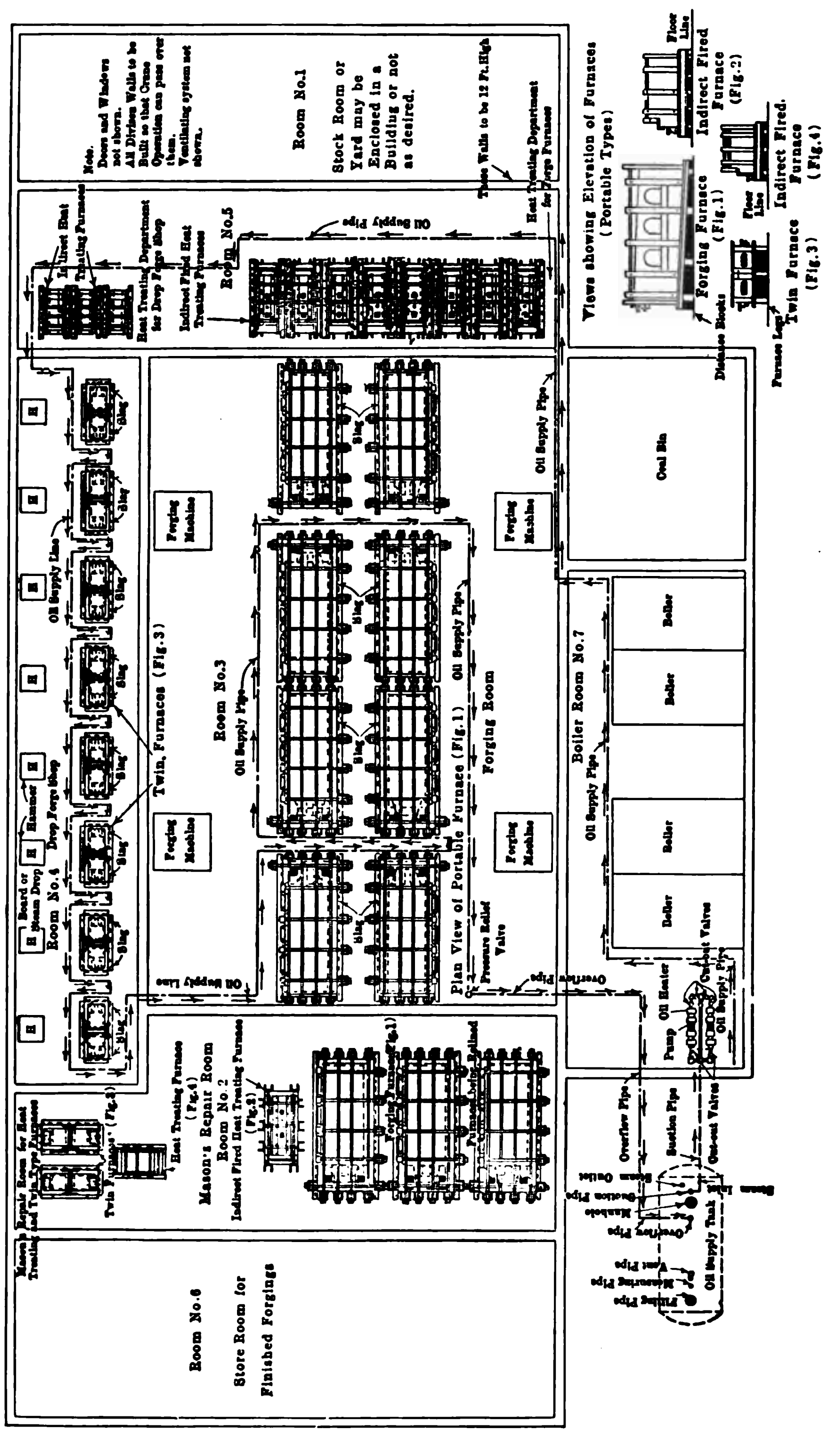


FIG. 57.—A modern forge shop.

Room 1. Stock room. 2. Masons' room where the furnaces are repaired by masons and kept in stock for immediate use. 3. Forging room. 4. Drop-forging room. 5. Heat-treating room. 6. Store room. 7. Boiler room.

In large forging plants, it requires 82 gallons of oil to represent a long ton of coal. In small drop-forging furnaces, it requires 62 gallons of oil to represent a long ton of coal.

In flue-welding furnaces, welding safe ends of locomotive flues, only 58 gallons of oil are required to represent a ton of coal. The reason for this is obvious; viz., a welding heat cannot be made with a green fire. The fire must be coked, and this involves a loss of volatile matter from the coal, as well as a loss of valuable time while coking the coal. In practice 6 gallons of oil represent 1000 cubic feet of natural gas, the gas having a calorific value of 1000 B.t.u. per cubic foot. Likewise 3½ gallons of oil equal 1000 cubic feet of commercial or water gas, having a calorific value of 620 B.t.u. per cubic foot.

The coal referred to has a calorific value of 14,000 B.t.u. per pound and is figured by the long ton (2240 pounds); the oil has a calorific value of 19,000 B.t.u. per pound and weighs 7½ pounds per gallon.

The manufacturers in the section of our country located along the Atlantic coast, will be compelled to use oil of low gravity coming from Mexico, where it is produced in great quantities. This varies in gravity from 11° Bé. to 16° Bé., but averages about 12° Bé. As this oil is high in sulphur content, combustion chambers must be used in order to eliminate the sulphur as much as possible. With the proper oil installations or systems, this fuel is readily burned, but it must be heated to reduce its viscosity. Mexican oils of 16° Bé. gravity vaporize at approximately 175° F. and should be heated to about 170° F. The lower oils of 11° Bé. to 12° Bé. gravity vaporize at 200° F. or 210° F., and should be heated to within 5° of their vaporizing point.

California oil of from 14° Bé. to 16° Bé. gravity vaporizes at 230° F. and should be heated to 225° F.

Texas oil which is approximately of 21° Bé. gravity vaporizes at 142° F. and should be heated to 5° F. less than the vaporizing point.

Oklahoma fuel oil vaporizes at approximately 154° F. and should be heated to 149° F.

The question is often asked: " What is the vaporizing point of oil from 21° Bé. to 23° Bé. gravity? " This question cannot be answered without asking the question: " From what field is this oil taken?", because an oil of 21° Bé. gravity may be a mixed oil. If a mixed oil, it would be 50 per cent Mexican oil of about 16° Bé. gravity and 50 per cent Pennsylvania oil, which is about 36° Bé. gravity. This will make 21° Bé. gravity oil. Sometimes 23° Bé. gravity oil is made by mixing 40 per cent of the Mexican oil and 60 per cent of the Pennsylvania oil. These oils vaporize at approximately 140° F.

Oil as Fuel in Boiler Manufacturing and Repair Shops

Oil is an incomparable fuel in the making or repairing of boilers, as an even heat can be procured in the furnace. This is absolutely essential in the heating of plates for bending, for if they are unevenly heated there will be a distortion in the plate which cannot be removed.

Another advantage in using oil as fuel is the quickness of the heat. It is most important to turn out a maximum output when one considers the fact that a number of men are required to operate the press and these men are idle until the metal is heated. Within a period of thirty minutes in the morning the plates may be heated evenly and withdrawn from this type of furnace. (Fig. 62.)

To-day, boiler shops desire to make their own rivets. The entire bar is usually charged in, the machine being convenient to one end of the furnace. The man operating the rivet-making machine fits the blanks into the machine. Another man charges the cold stock into the furnace from the rear end. By the use of oil as fuel in this practice a perfectly even heat is maintained throughout the length and width of the furnace. (See Fig. 63.)

In the operation of a bolt riveter it is necessary to heat the rivets quickly. The author always recommends a two-door furnace for this purpose, similar to that shown in Fig. 65.

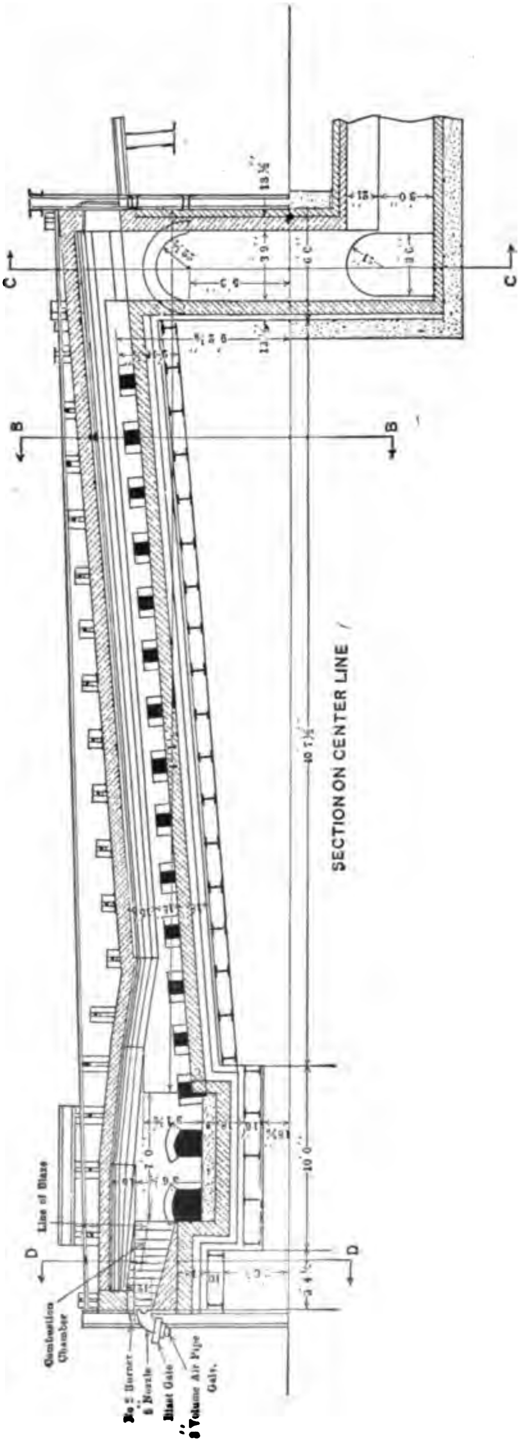


FIG. 58.—Oil-fired continuous declined-hearth billet-heating furnace.

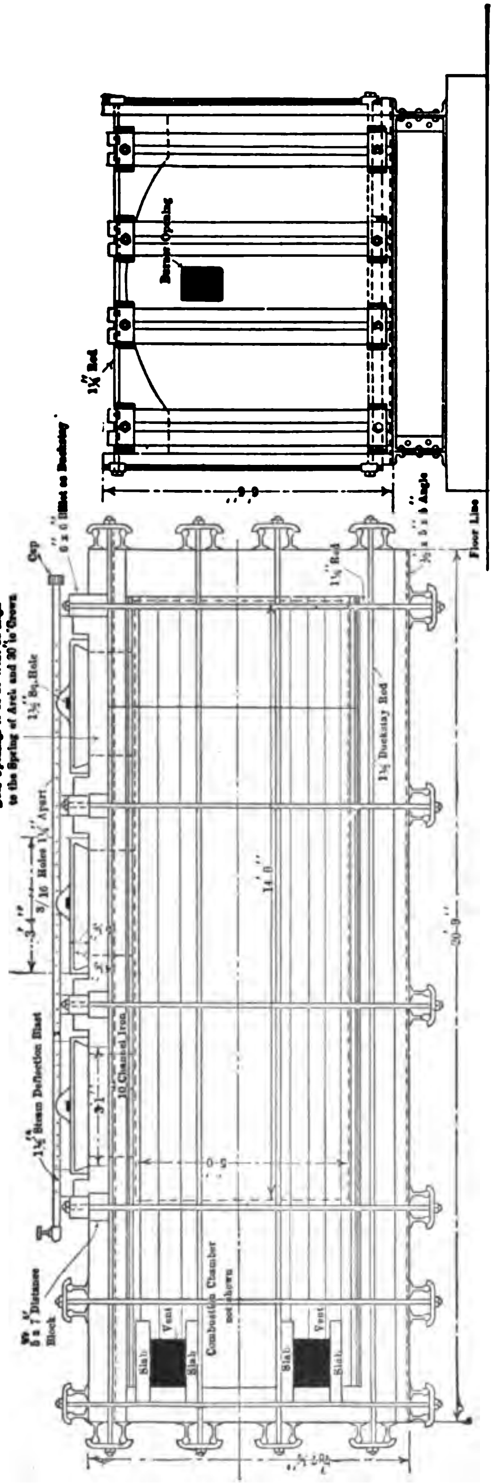


FIG. 59.—Portable billet-heating furnace, three-door type.

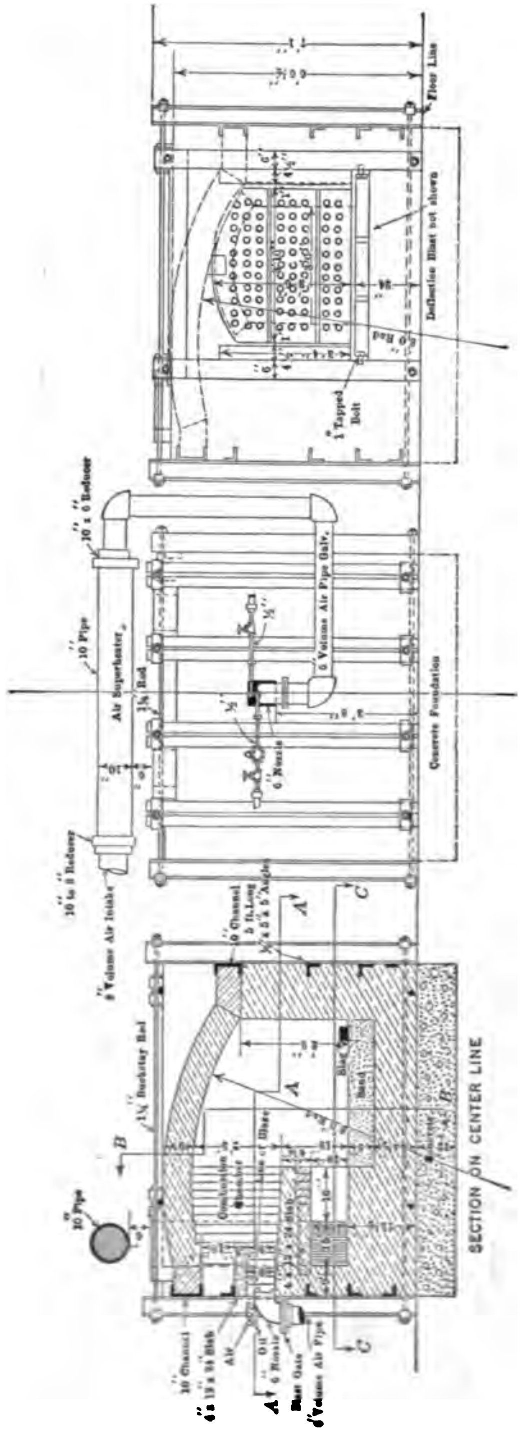


FIG. 60.—Billet-heating furnace.

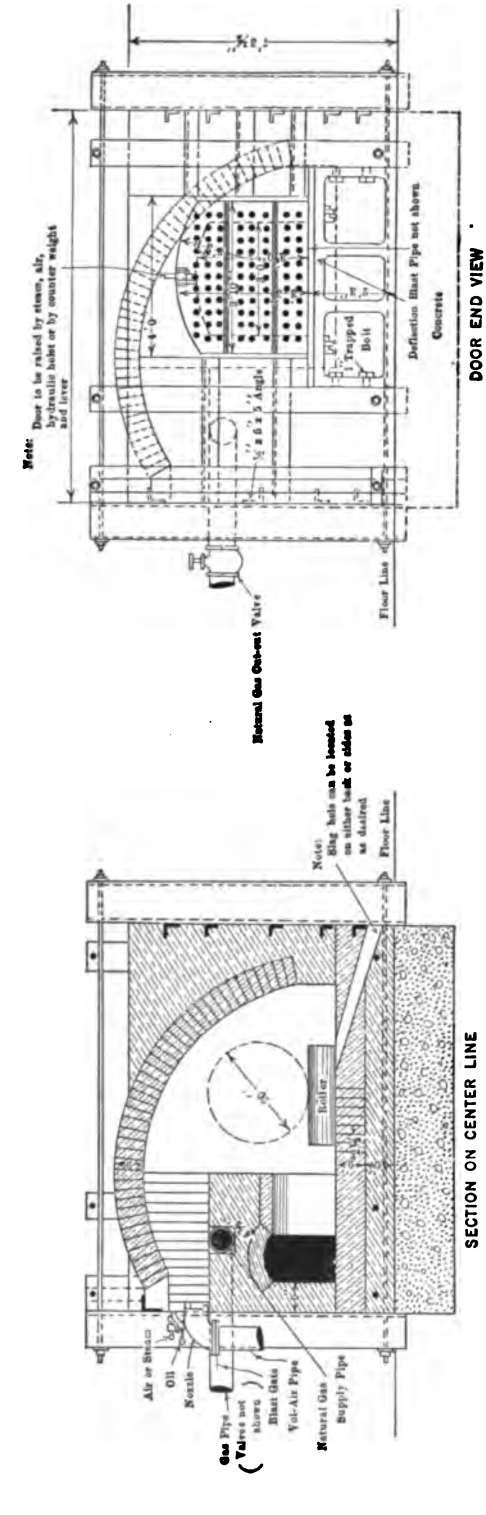


FIG. 61.—Modern billet-heating furnace for use of oil in combination with gas, or either fuel exclusively.

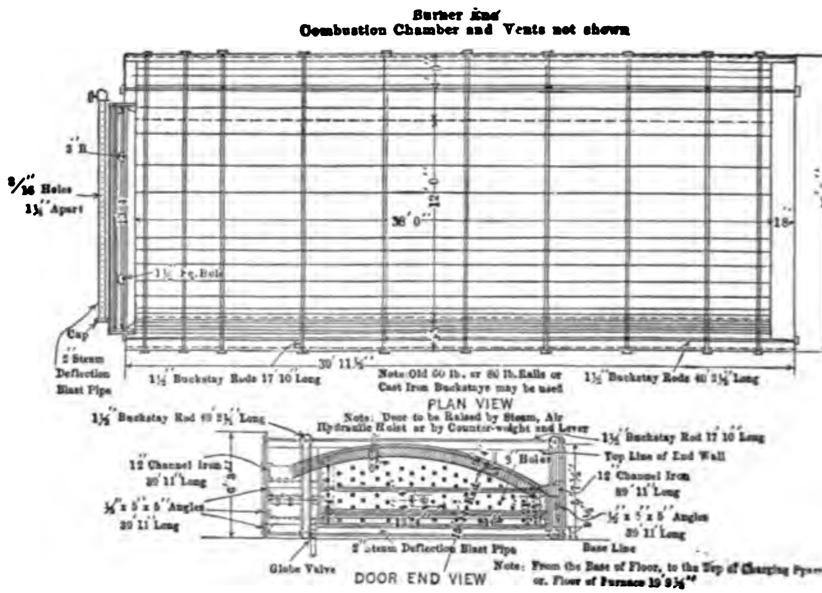


Fig. 62.—Plate-heating furnace 12 feet wide by 38 feet long.

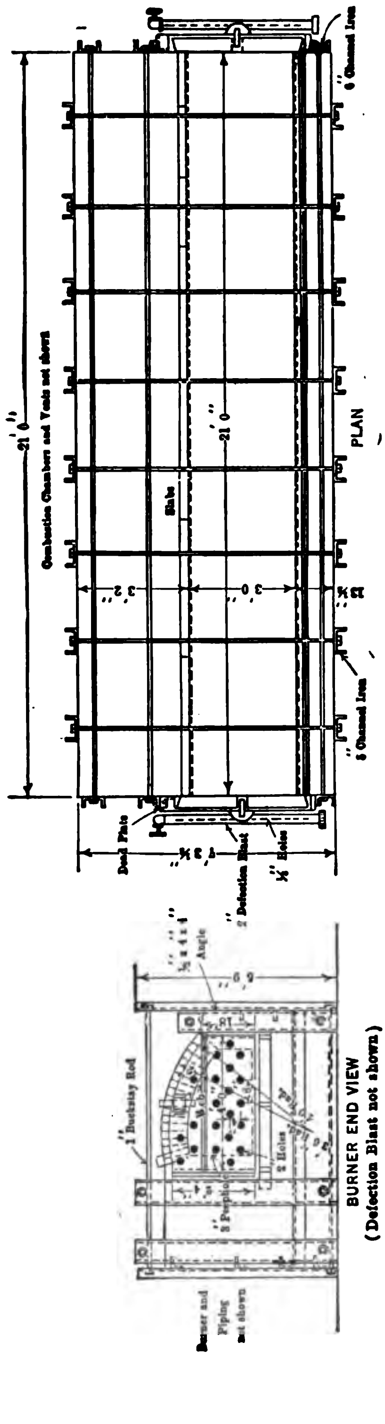


FIG. 63.—Rivet-making furnace.

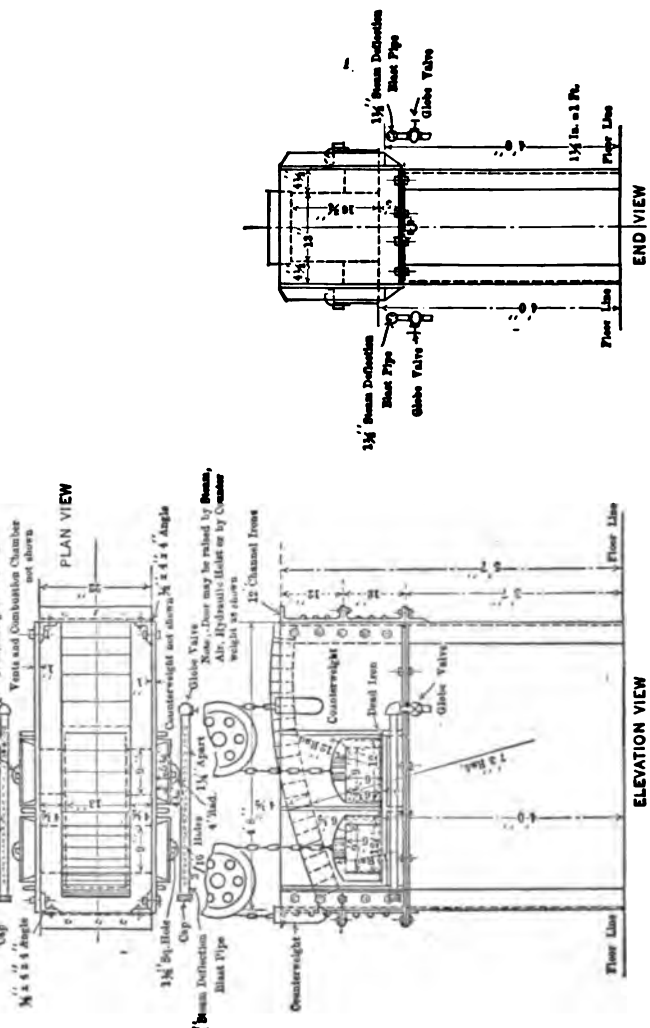


FIG. 64.—Large double-door rivet-heating furnace.

In the heating of rivets it is very essential to reduce the scale on the metal to the minimum. For this purpose it is recommended that the combustion chamber be of adequate proportions to reduce this scale. If a furnace is not provided with a combustion chamber, it is necessary to use the furnace itself for this purpose and in so doing the metal is oxidized.

Oil Equipment for Heat-Treating Furnaces

Note (Fig. 65) the graduated heat ports which deliver the heat from the lower combustion chamber to the charging space immediately above. These heat ports must vary in proportion to the size of the furnace and temperature maintained. Without these graduated heat ports, it is impossible to obtain an even distribution of heat throughout the length and width of the charging space.

Note the graduated heat ports in Fig. 66. Only one burner is used in the operation of this furnace.

The furnace in Figs. 67 and 67*a* is provided with graduated heat ports which insure the even distribution of the heat throughout the entire length and width of the charging space, and can be operated without a variation of 10° F. in any portion of the furnace.

Steel is valuable only when it is properly heat-treated, and it is therefore very important to have an even distribution of heat. Ordinarily only one burner should be used; but, of course, it is sometimes necessary, in car type furnaces, to use two burners. However, only one burner is used in each of the combustion chambers placed on each side of the car.

In heat-treating furnaces with high temperatures, 63 gallons of oil represent a long ton of coal. In heat-treating furnaces with low temperatures for drawing purposes only 58 gallons of oil are required to represent a long ton of coal.

The coal referred to has a calorific value of 14,000 B.t.u. per pound, and is figured by the long ton (2240 pounds); and the oil has a calorific value of 19,000 B.t.u. per pound and weighs 7½ pounds per gallon.

Oil as Fuel in Steel-foundry Practice

In Fig. 68 the process is a very simple one. The oil burners are placed one on each side, but only one burner is in operation at a time. It is necessary to put in what is known as a " dog house." This is done by building a wall from the end of the furnace up to the roof or arch as shown in plan and end views. Usually, however, the original gas port is covered and the air ports on each side are enlarged as shown in Figs. 69 and 69*a*.

The waste gases are delivered through both the original gas and air regenerators. In ordinary practice three heats are taken from an open-hearth furnace using oil as fuel, but usually only two heats are taken from an open-hearth furnace when using producer gas.

In steel-foundry practice it is very essential that the ladles be carefully heated as nearly as possible to the temperature of the steel when it is poured into the ladle. The author always recommends the use of a combination burner and furnace. (Fig.71.) The function of the furnace attached to the burner is to aid in maintaining a very low fire when the ladle has been patched. The burner should always have both a minimum and a maximum capacity adequate for demands required of it—either for maintaining a light fire or forcing it to bring the refractory lining of the ladle to a higher temperature. The author always recommends a cover for a ladle; it is poor practice to make heat and then waste it.

The burner should be provided with swivel joints and counterweight so that it can be raised to clear the ladle when the ladle is removed.

It is also very important in steel-foundry practice to use oil to dry molds, for they

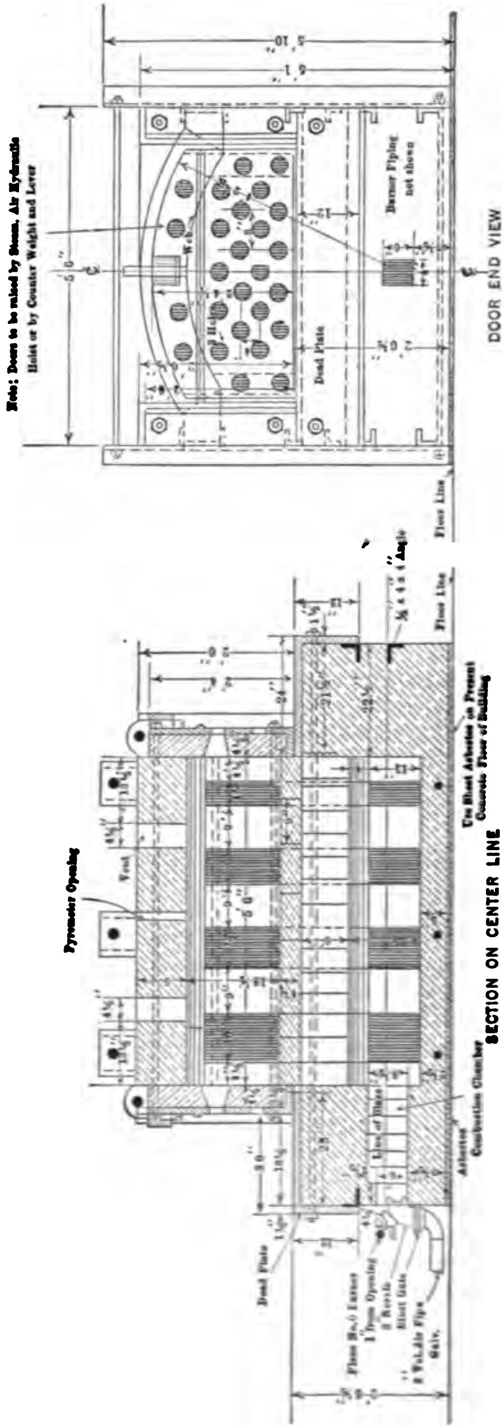


FIG. 65.—Stationary heat-treating furnace, semi-muffle type.

can thus be dried in one-quarter the time ordinarily required when using coke. Again, when using coke as fuel it is impossible to get an even distribution of heat at the lower portion of the oven no matter what may be the size of the oven. The oven may be 45 feet long by 20 feet wide by 12 feet high. Only one oil burner should be used, and there should also be a long combustion chamber with graduated heat ports to insure an even distribution of heat at the base of the oven as shown in Fig. 72.

As moisture and waste gases naturally ascend, a vent should be provided in the roof of the mold-drying oven so that the moisture and waste gases will pass out of the oven by a natural and sane method. Many superintendents state that they do not want to heat up the molds quickly because of the danger of burning them. They are right if they have in mind the use of coke or hard coal—their premises are absolutely correct with that kind of fuel, but absolutely incorrect in referring to the more modern *oil* fuel. because with oil an even distribution of heat can be obtained; whereas with coke or coal as fuel the heat is localized. Only one burner should be used in an oven.

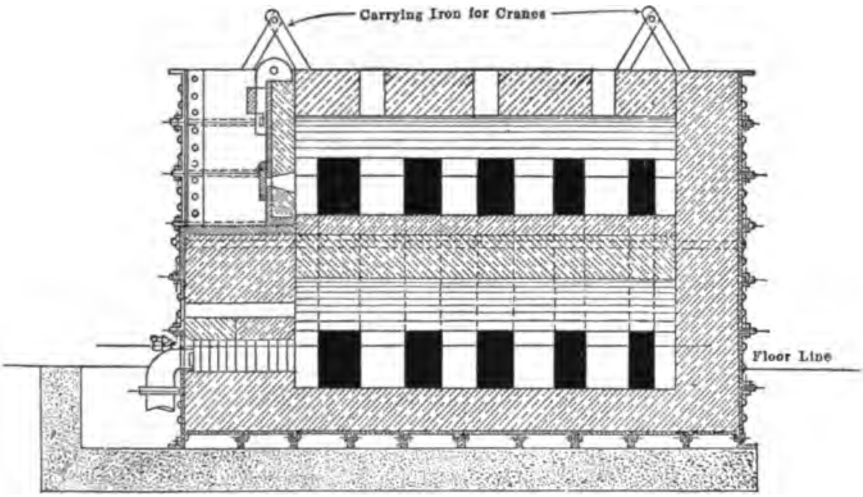


Fig. 66.—Portable heat-treating furnace, semi-muffle type.

Oil as Fuel in Malleable-iron Foundry Practice

Fig. 73 shows an air furnace changed from coal firing to oil. The volume air pipe is removed from the ash pit where it ordinarily delivers forced air through the grates and thence through the charge of coal. It is connected with the 12-inch nozzle shown immediately under the burner. It will be noticed that the furnace is operated with one burner and the volume air must pass through the flame. The combustion chamber which is constructed in the interior of the firebox is of adequate proportions to insure the oil and the atomized fuel being mixed and "reduced to heat" before reaching the furnace proper. Otherwise, the charge would oxidize, and slag instead of iron would be tapped off.

It is necessary to use but the one burner and have the flame of the burner fit the combustion chamber perfectly. Otherwise, there will be a great loss of metal because of oxidation.

The author prophesies that in a few years many thousands of these furnaces will be used for the melting of gray iron, as a very much superior iron can be produced in an air furnace than can be hoped for in a cupola. Everyone knows that gray iron is the most

unruly of all the family of metals. The variation of temperatures makes a varying quality of metal; in fact, if it varies 200° F. it becomes a new metal. Its nature has changed from, say, 2350° F. to 2550° F. Again, a certain alloy of metal can be charged in and another alloy of metal taken out. When using oil as fuel, a temperature can be

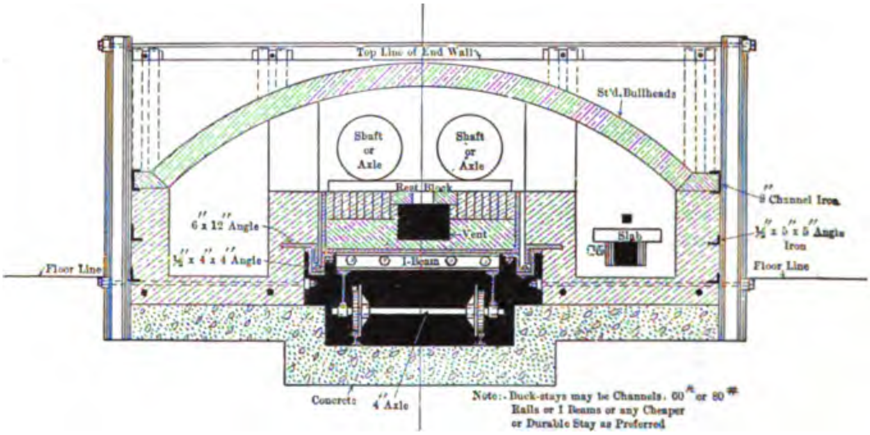


Fig. 67.—Car-type shaft annealing furnace of modern design, view showing two shafts or axles in the furnace.

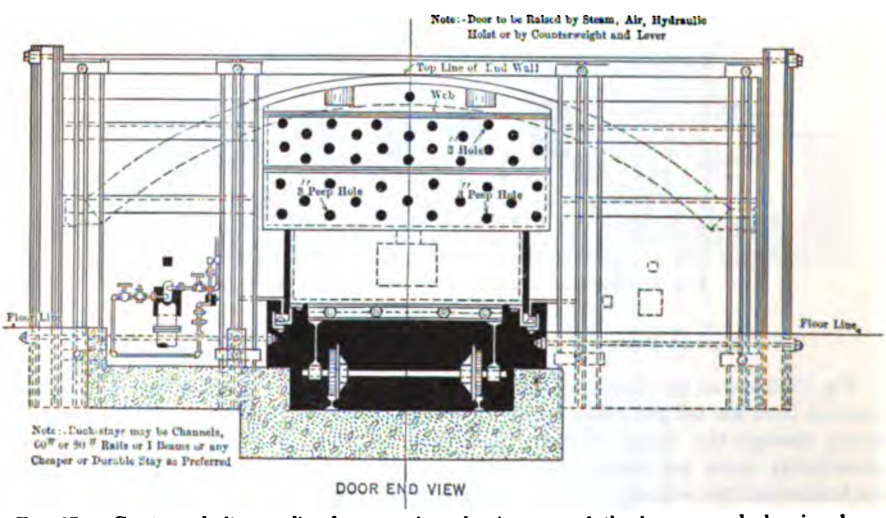
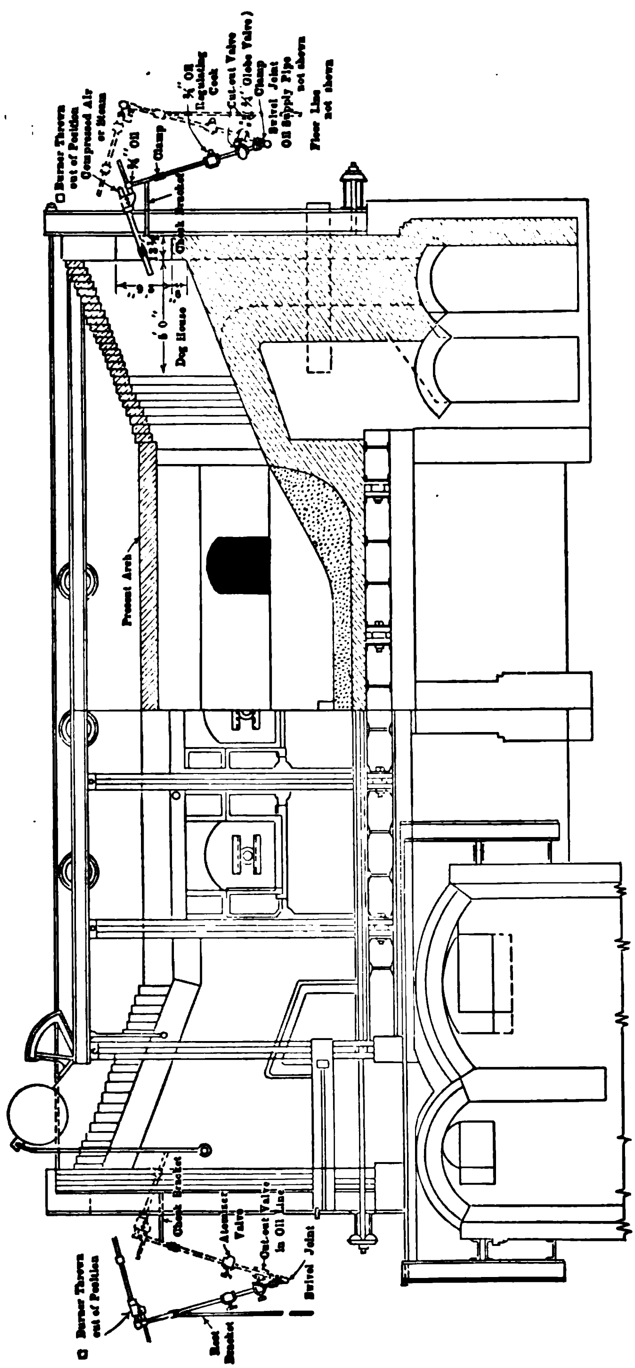


Fig. 67a.—Car-type shaft annealing furnace, view showing one of the burners and charging door closed.

maintained not varying more than 20° F. each day. Of course with coal and coke nothing like that could be hoped for. The furnace can be charged and the burner started at a certain hour with oil and the metal tapped out at a certain hour without a variation in time of more than ten minutes, no matter what may be the climatic conditions. It is always figured that 20 feet of stack is equal to $\frac{1}{10}$ of an inch draft, providing it is a clear day. The effect of rain, snow or fog on draft conditions is readily seen when burning coal; but in the burning of oil any temperature desired can be maintained, for it is not a question of how much heat can be made but of how much heat is wanted.



OIL EQUIPMENT OF OPEN HEARTH FURNACE

FIG. 68.—Gas-fired open-hearth furnace changed to oil-fired.

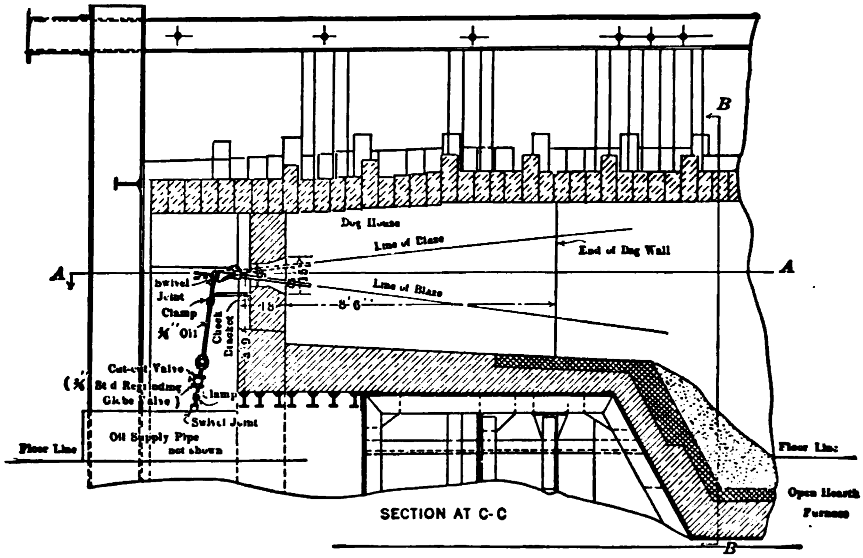


Fig. 69.—Open-hearth furnace equipment, one of the burners shown in operation.

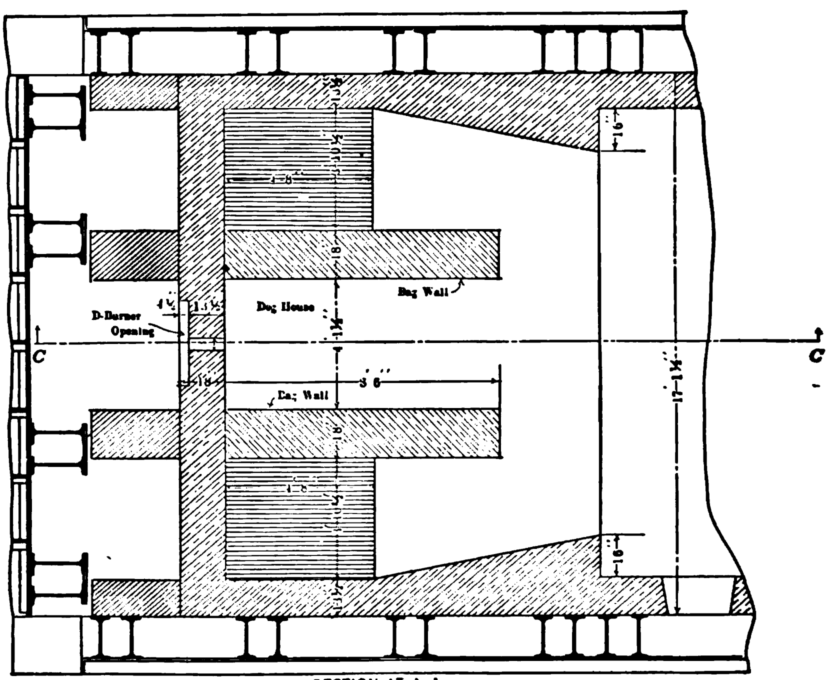


Fig. 69a.—Open-hearth furnace equipment, plan view showing dog-house at burner end.

It is also prophesied that in a few years the present coal-fired annealing furnace will be a thing of the past, owing to the fact that these furnaces often vary in temperature 350° F., the waste gases passing through and under the floor. The theory is that they heat the floor, but they cannot possibly do so.

The author is very familiar with the present practice of charging the light-weight castings in the lower box and the larger and heavier castings into the upper box. Some day this practice will not be permitted. There will be specifications from the buyers of

View A. Open-hearth burner in operation, in a vertical position.

View B. Open-hearth burner not in operation—moved out of position by the aid of swivel joints.

FIG. 70.

castings stipulating that the temperature of the furnace must not vary more than 150° F. in any portion. This can be done with oil as fuel, but it cannot be done with coal or coke.

The author wishes to make himself clearly understood. It is one of the most dangerous of shop practices for manufacturers to use any kind of a heat-treating furnace that does not attain and maintain practically an even heat throughout the entire furnace, because proper results cannot be obtained with such a furnace.

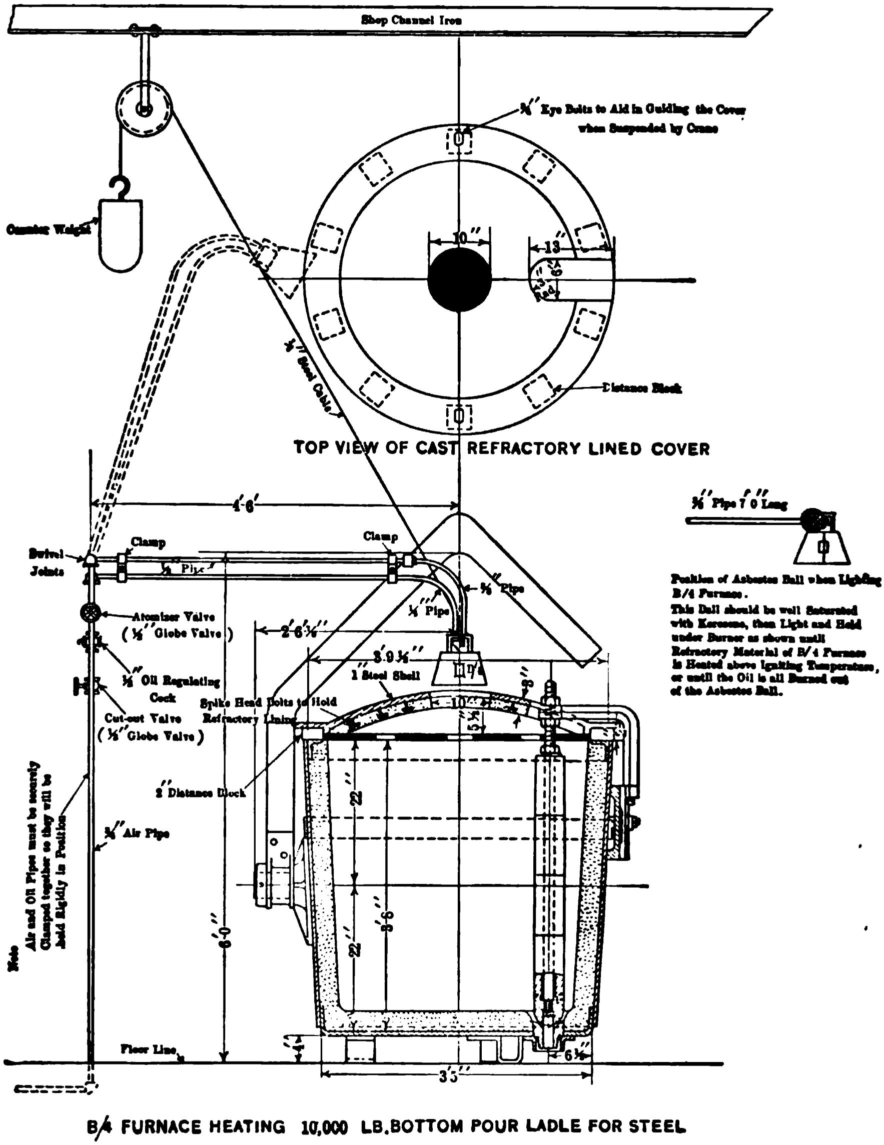


Fig. 71.—Apparatus for heating large ladles in steel foundries.

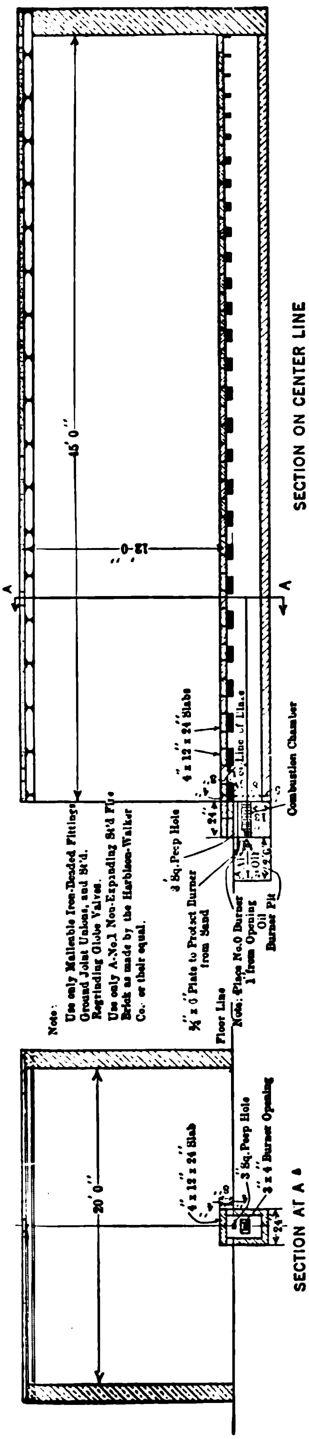


FIG. 72.—Mold-drying oven.

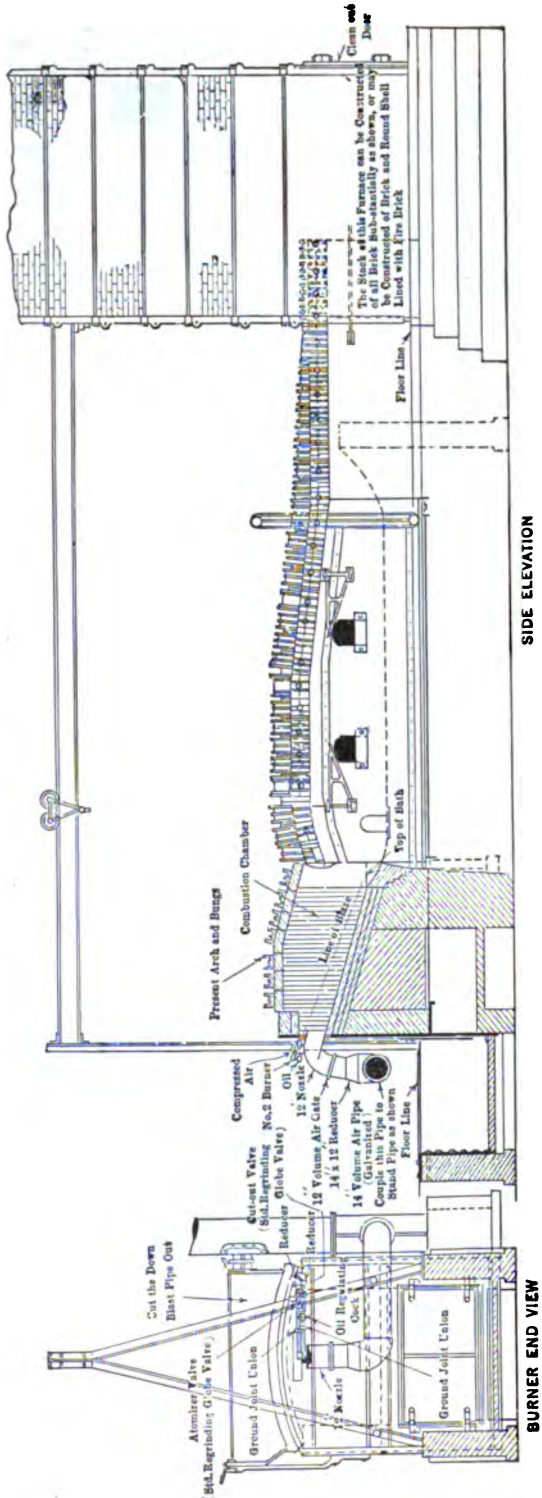


FIG. 73.—Air furnace used in melting metal for malleable-iron castings.

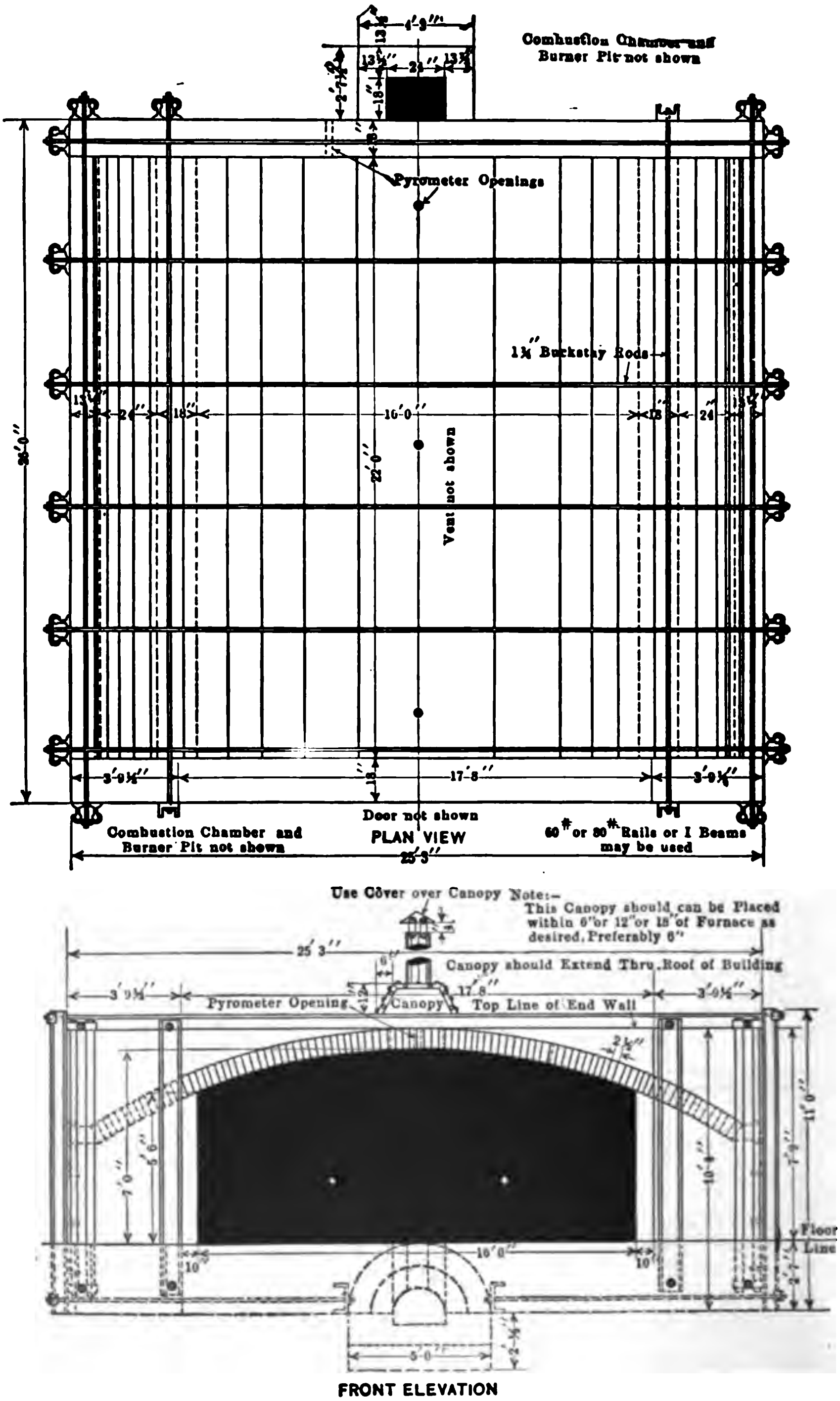


FIG. 74.—Modern type oil-fired annealing furnace.

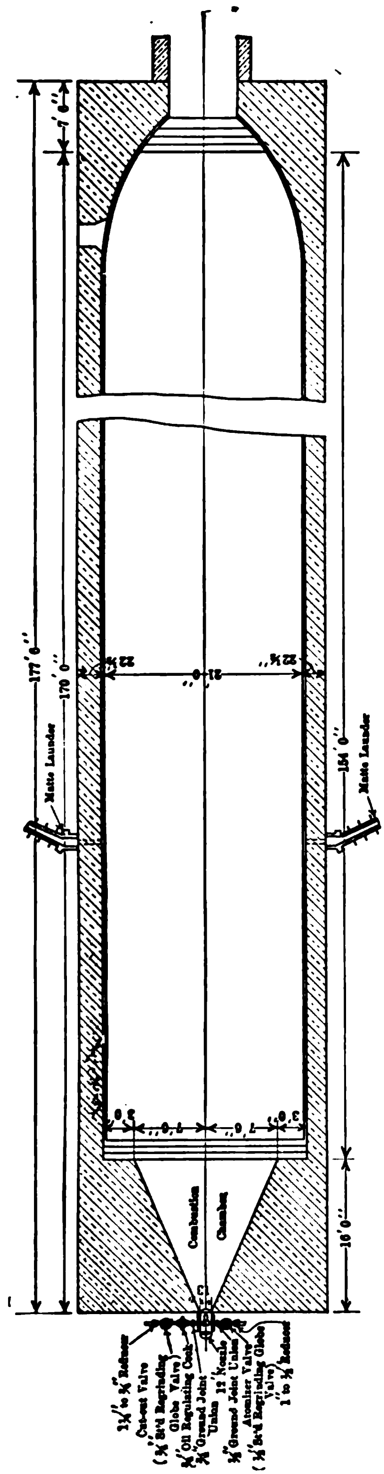


FIG. 75.—Copper-matting furnace having bath 21 feet wide by 154 feet long, and operated with one oil burner.

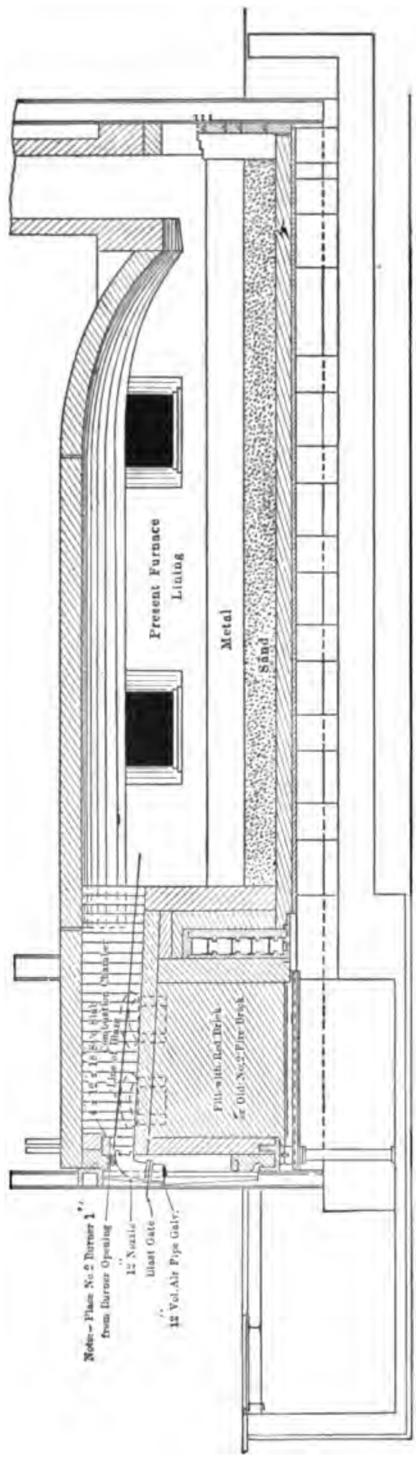


FIG. 76.—Two hundred and fifty ton copper-refining furnace of modern construction operated with one oil burner.

Oil as Fuel for Copper Matting and Refining Furnaces

When there are about 6 inches of copper in the bath as in Fig 75, it is tapped out through the landers and, of course, decomposed by water. The slag is hoed from the door near the flue end of the furnace and hauled down to a dump by a small locomotive. Oil is an excellent fuel for this class of service.

All copper-refining furnaces should be operated with oil and only one burner should be used, for in this way it is possible to have perfect control of the temperature of the furnace and to carry an oxidizing flame during the course of the refinement. (See Fig. 76.) After the copper has been greenpoled and refined to 99.60 per cent purity, the burner in combination with the combustion chamber can be operated so as to produce a perfectly neutral flame.

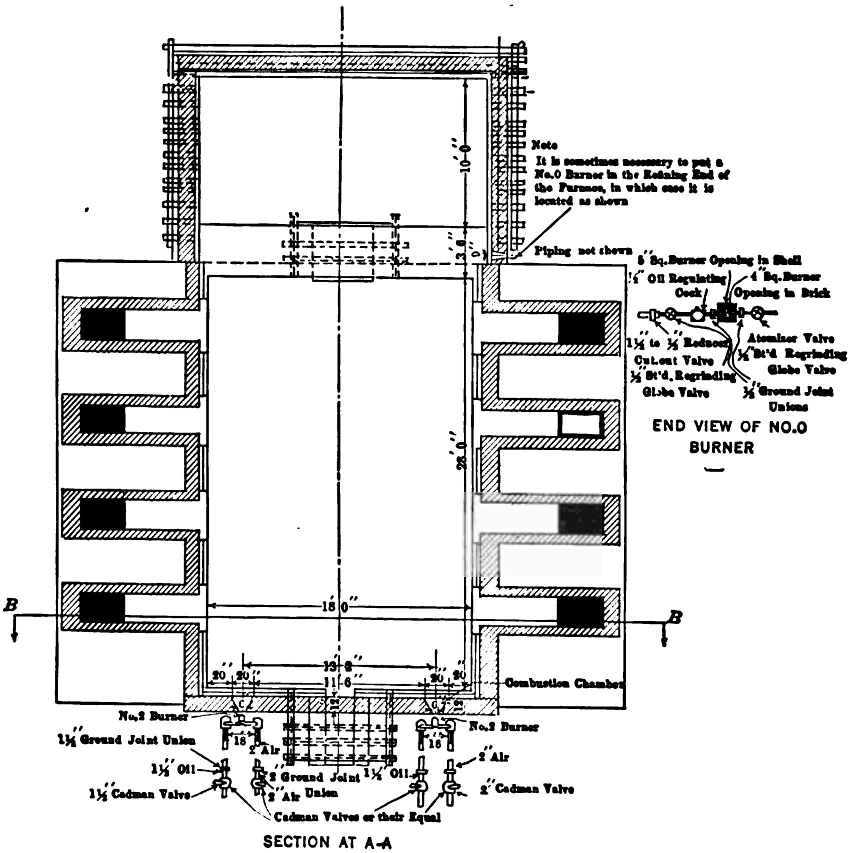


Fig. 77.—Regenerative glass furnace 18 feet wide by 28 feet long, operated with two oil burners.

Oil as Fuel in Glass Industry Equipment

Each burner should be of adequate capacity for the demands upon the furnace, and should be so placed as to deliver the flame in front of the regenerative ports, substantially as shown. Of course, only one burner is operated at a time.

In Fig. 78, note that the burner is placed immediately under the arch and delivers sufficient heat to anneal the ware while passing through the lehr.

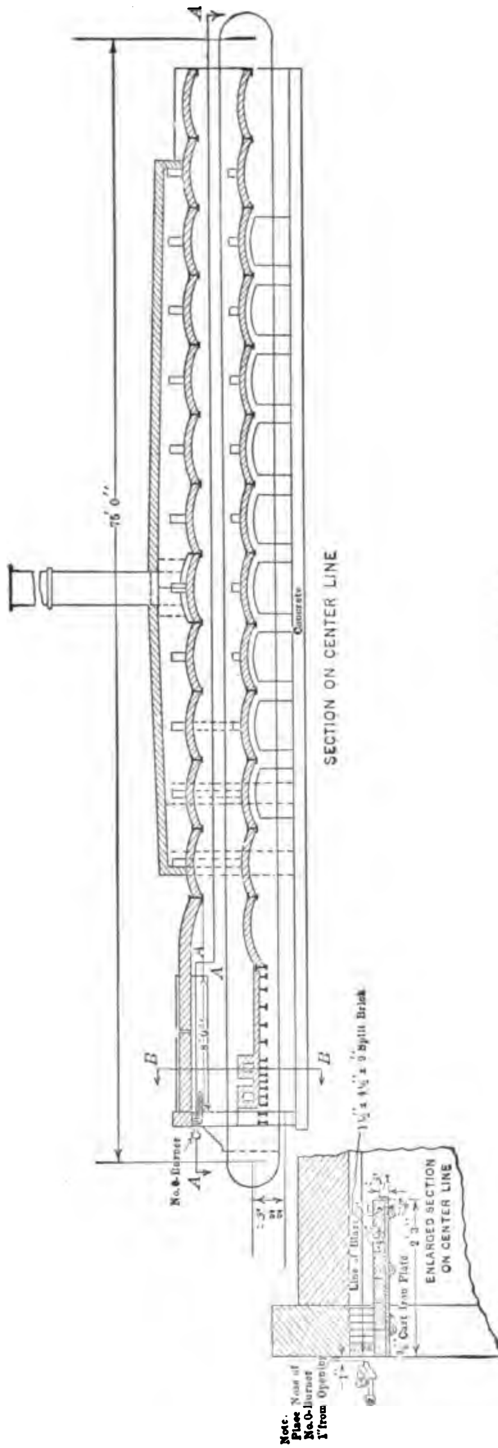


Fig. 78.—Oil equipment for glass lehr.

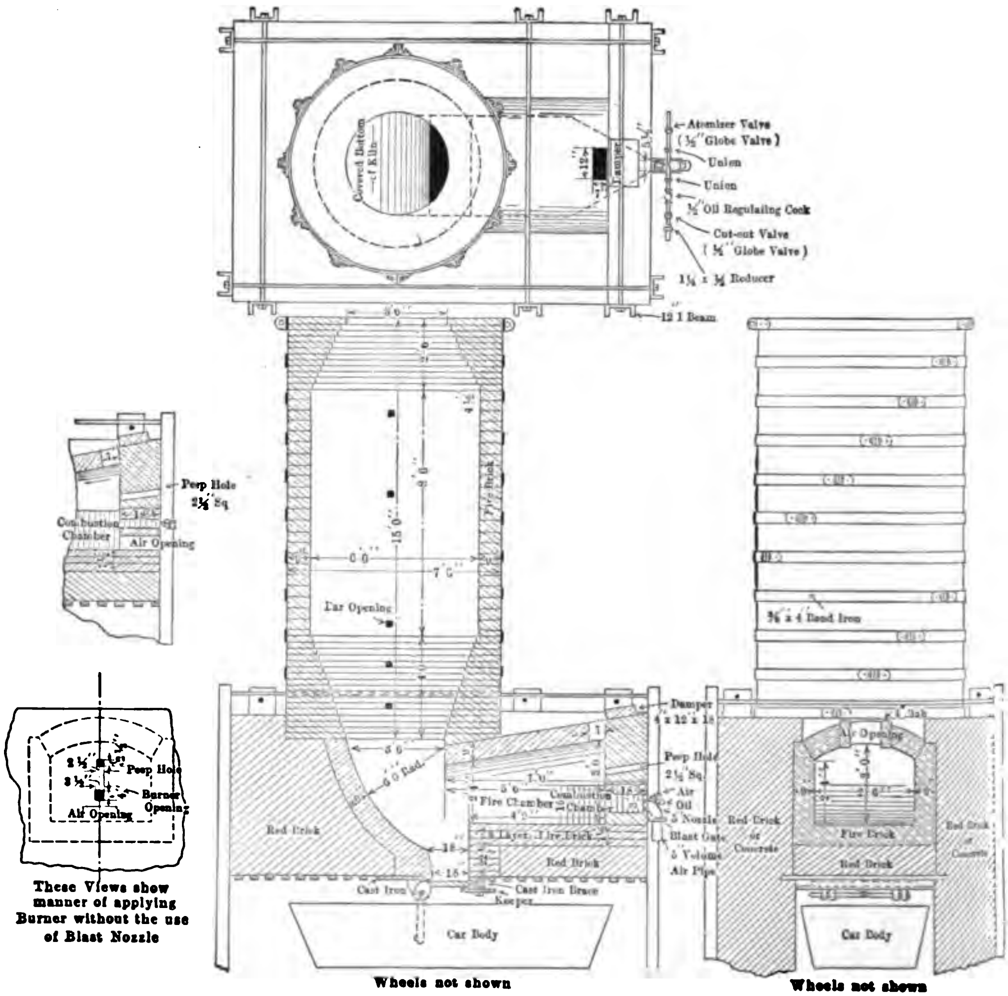


Fig. 79.—Vertical-type lime kiln.

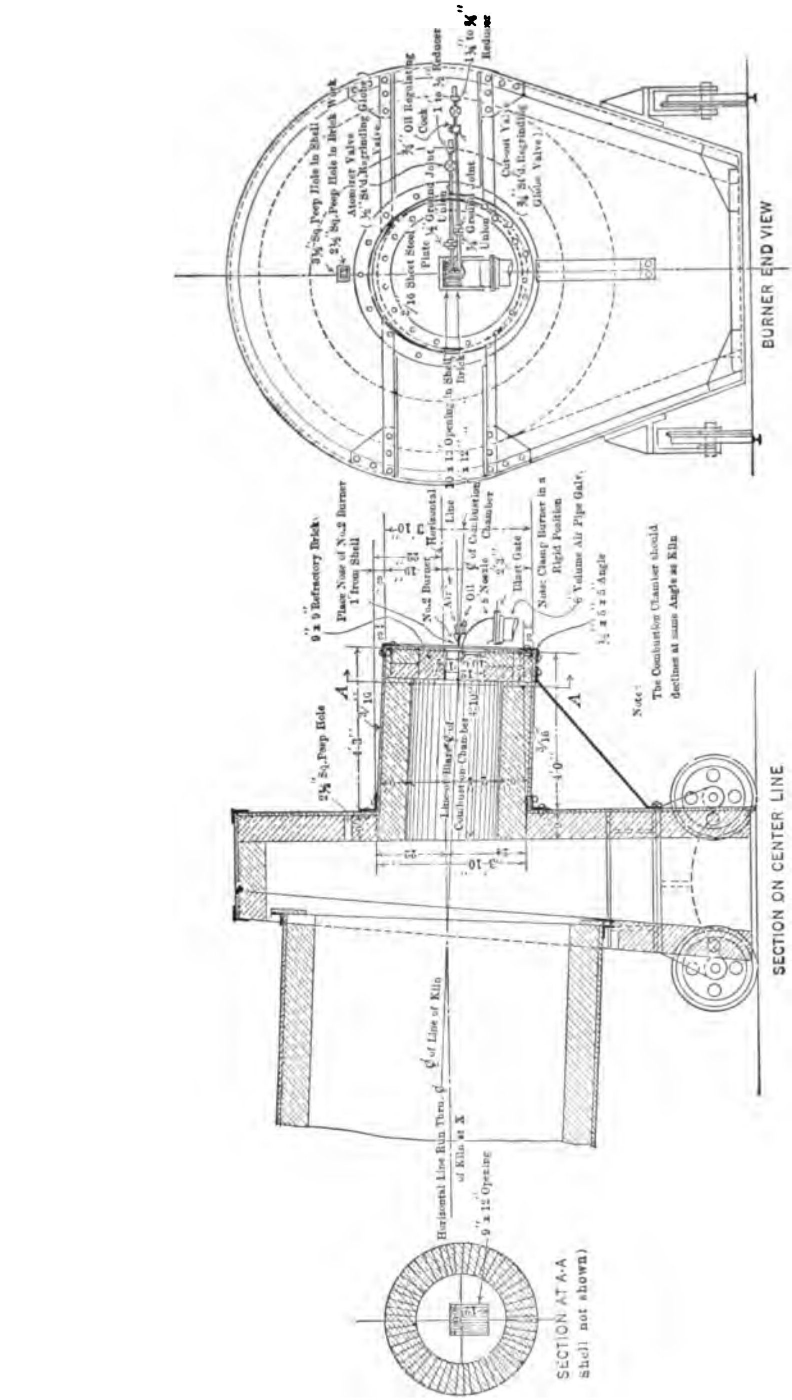


FIG. 80.—Rotary lime kiln.

OIL AS FUEL IN LIME KILNS (See Figs. 79 and 80.)

Oil is very a excellent fuel for this class of service owing to the increased output and higher grade of lime. The sulphur content in the oil does not have any effect upon the material even though the oil contains as high as 3.85 per cent sulphur.

By the use of one burner the heat can be delivered in any portion of the kiln, and with oil either a very long flame or a very short flame may be had as desired.

OIL AS FUEL FOR CEMENT KILNS AND DRYERS (See Figs. 81 and 82.)

Oil is an excellent fuel for this purpose, but in some sections of the country it cannot compete with pulverized coal. Pulverized coal is an ideal fuel in the manufacture of cement.

In nearly every country on the face of the globe there are millions of tons of graphitic or other coal of very low calorific value. The pulverized coal is delivered to the hopper and fed in the manner shown in Fig. 83 upon the flat sheet of steam or compressed air produced by the oil burner. By this method it is carried through the combustion chamber and therein consumed, the heat being delivered into the furnace. Of course, all coals must be dried and pulverized in the usual manner employed in the pulverization of coal. By this method the proper quantity of graphitic coal or other low-grade coal can be delivered to the furnace, using, say, 20 per cent oil and 80 per cent coal. The flat flame produced by the oil burner supplies the oil as well as the force for carrying the pulverized coal through the combustion chamber.

The largest deposits of graphitic coal in the United States are around Providence, R. I. This coal has a calorific value of 7840 B.t.u. per pound.

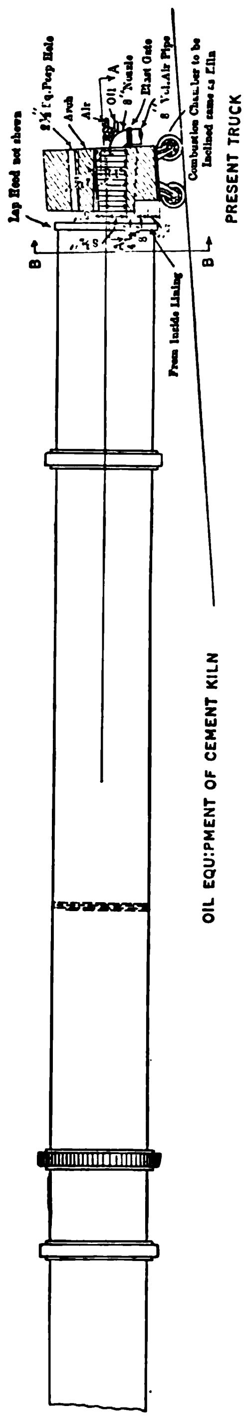


Fig. 81.—Oil equipment for rotary kiln.

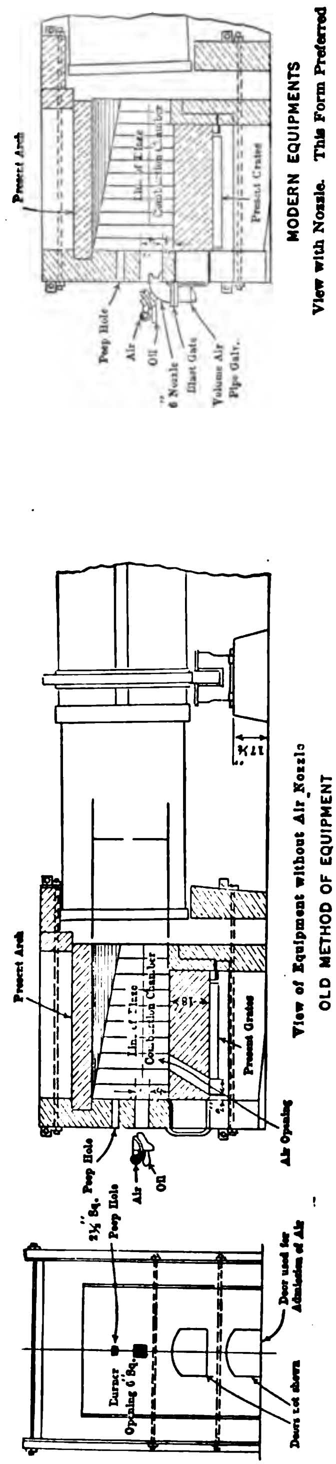


Fig. 82.—Rotary dryer as used in chemical works, for sand-drying, etc.

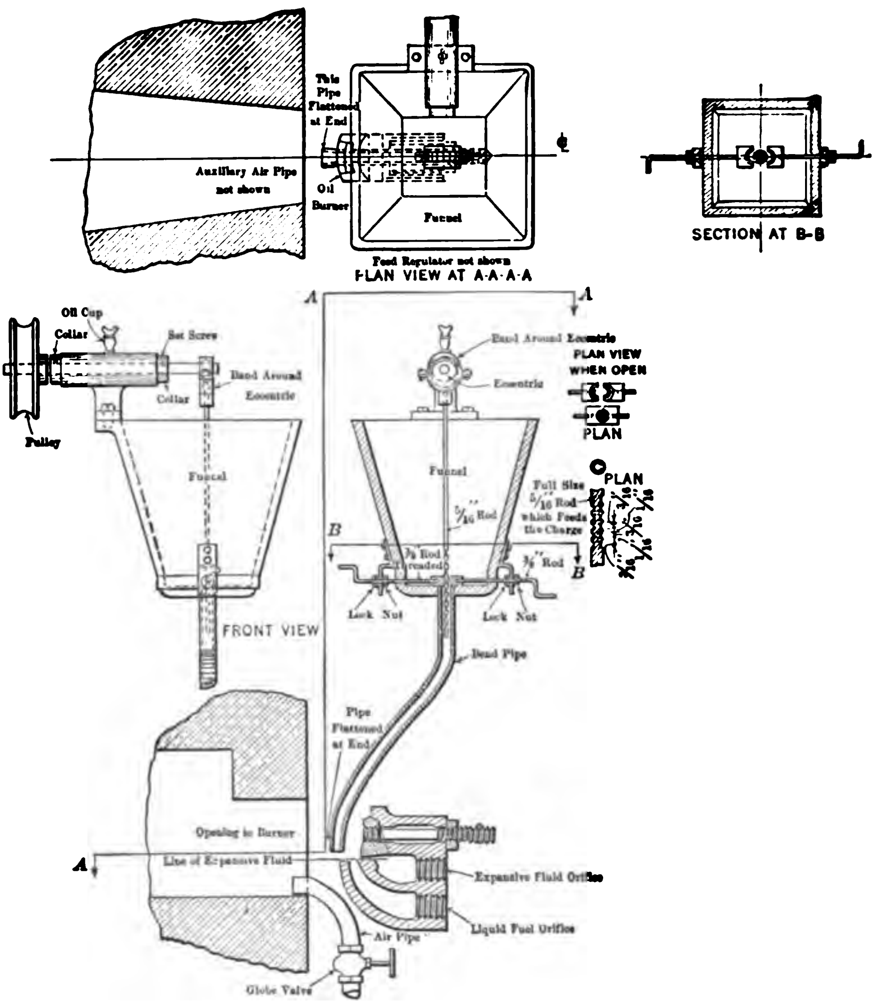


Fig. 83.—Method of burning liquid fuel in combination with pulverized or graphitic coal, for melting, forging and heating furnaces.

INTERNAL-COMBUSTION PETROLEUM ENGINES

BY

ARTHUR H. GOLDINGHAM

Engines designated by, and included in, the above classification comprise: (*a*) the "hot-surface" oil engine, both high and low pressure, (*b*) the Diesel engine, with solid and air-blast injection, (*c*) gasoline (or petrol) engines, (*d*) natural-gas engines.

Definition.—An internal-combustion petroleum engine is a self-contained unit arranged to receive within its cylinder, vaporizer or combustion space, by varying methods in different types (hereinafter described and illustrated) either liquid heavy crude and fuel oil, petroleum, distillates or other similar fuels. Such products are first vaporized and intimately mingled in the combustion space with air compressed by the inward movement of the piston of the engine. Ignition of the explosive mixture thus formed then takes place with consequent evolution of the heat energy contained in the fuel which is thus converted into work. With the light, highly volatile fuels, gasoline, benzol and lighter distillates, a simpler process, that of carburetion is followed, that is, the air in passing to the engine cylinder absorbs the fuel vapor as hereinafter fully explained.

Historical.—In 1791 John Barber first attempted to obtain motive power from inflammable gas and in 1794 Robert Street built the first English internal-combustion engine with cylinder and piston. In 1799 Philip Lebon patented in France a gas engine using compression of gas and air before ignition and in 1823 Samuel Brown produced a successful hot-air engine. In 1838 Barnett and in 1860 Lenoir introduced improved types, while in 1862 Beau de Rochas patented his well-known cycle requiring four strokes of the piston for its completion. Otto in 1863 and Langen in 1866 produced the Otto and Langen free-piston gas engine. In 1870 Julius Hock in Vienna produced the first practical petroleum engine and Brayton in the United States about 1873 produced his first compression oil engine. The Priestman engine of 1885 was followed by the Hornsby-Akroyd type of 1886–1890.[1] The development of the oil engine and the increase in its efficiencies at different periods are recorded in Fig. 1 showing typical indicator diagrams from various engines with the results obtained.[2]

First principles.—This subject will be referred to here chiefly in extracts from Clerk.[3] Rankine defined thermodynamics, thus: "It is a matter of ordinary observation that heat, by expanding bodies, is a source of mechanical energy, and conversely that mechanical energy being expended either in compressing bodies or in friction is a source of heat. The reduction of the laws according to which such phenomena take place, to a

[1] For detailed history, see Gas and Petroleum Engines, by W. Robinson.

[2] Reproduced from The Heavy Oil Engine, Goldingham, A. S. M. E. Transactions, 1915.

[3] Thermodynamics of the Gas, Petrol, and Oil Engine, by Sir Dugald Clerk.

physical theory or connected system of principles, constitutes what is called the science of thermodynamics." When work is transformed into heat, or heat into work, the quantity of work is equivalent to the quantity of heat. *Joule's equivalent* allows 778 foot-pounds as equivalent to 1 B.t.u., that is, the quantity of heat required to change the temperature of 1 pound of water 1° F., the temperature of the water being that of maximum density (39.4° F.).

Specific heat.—The amount of heat required to heat the unit weight of water through 1° is 1 heat unit, but the specific heat of any other body is the number of heat units required to heat the unit weight of a substance through 1°. Gases have two different

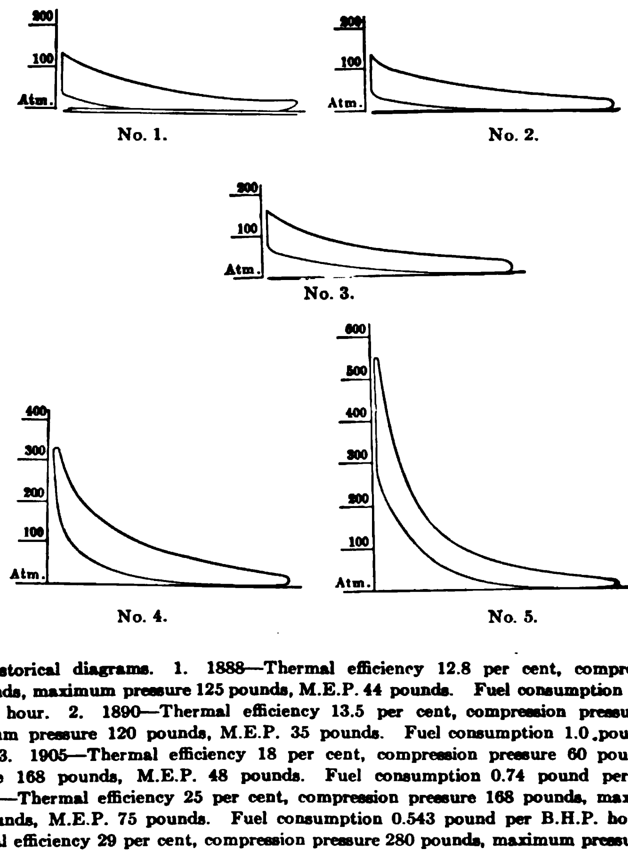


Fig. 1.—Historical diagrams. 1. 1888—Thermal efficiency 12.8 per cent, compression pressure 20 pounds, maximum pressure 125 pounds, M.E.P. 44 pounds. Fuel consumption 1.05 pounds per B.H.P. hour. 2. 1890—Thermal efficiency 13.5 per cent, compression pressure 40 pounds, maximum pressure 120 pounds, M.E.P. 35 pounds. Fuel consumption 1.0 pound per B.H.P. hour. 3. 1905—Thermal efficiency 18 per cent, compression pressure 60 pounds, maximum pressure 168 pounds, M.E.P. 48 pounds. Fuel consumption 0.74 pound per B.H.P. hour. 4. 1913—Thermal efficiency 25 per cent, compression pressure 168 pounds, maximum pressure 325 pounds, M.E.P. 75 pounds. Fuel consumption 0.543 pound per B.H.P. hour. 5. 1915—Thermal efficiency 29 per cent, compression pressure 280 pounds, maximum pressure 550 pounds, M.E.P. 70 pounds. Fuel consumption 0.46 pound per B.H.P. hour.

specific heats, (*a*) when heat is applied while the gas is at constant volume, or (*b*) at constant pressure. For gases used in the gas engine the two volumes are as shown in Table 1.

As the value of the specific heat varies with the temperature, it is best to define it with relation to the temperature. The volume occupied by a gas varies with regard to its temperature and pressure. By *Charles' law* all gases heated at constant pressure expand equally. One volume of gas at 0° C. if heated through 1° C. will expand $\frac{1}{273}$ and become $1\frac{1}{273}$ volume if the pressure is constant.

TABLE 1

Specific Heats of Gases to 200° C.—CLERK

(REGNAULT)

(For equal weights water = 1)

Name of gas	Specific heat at constant pressure	Specific heat at constant volume	$\frac{\text{Spec. heat const. pres.}}{\text{Spec. heat const. vol.}}$
Air	0.237	0.168	1.408
Oxygen	0.217	0.155	1.403
Nitrogen	0.244	0.173	1.409
Hydrogen	3.409	2.406	1.417
Marsh gas	0.593	0.467	.....
Ethylene	0.404	0.332	1.144
Carbonic oxide	0.245	0.173	1.416
Steam	0.480	0.369	1.302
Carbonic acid	0.216	0.171	1.165

If P = pressure for absolute temperature t and p' the pressure for t temperature also absolute, then

$$\frac{p}{p'}=\frac{t}{t'},$$

or if v be the volume at absolute temperature t and v' at t', then

$$\frac{v}{v'}=\frac{t}{t'}.$$

Boyle's law states that the product of the pressure and the volume of a perfect gas remains constant, if the temperature of the gas is unchanged, denoting pressure by p and volume by v.

Boyle's law is pv = constant.

If heat is supplied to a perfect heat engine at absolute temperature T and the absolute temperature of the source of cold is T', then the efficiency (E) of the engine is

$$E=\frac{T-T'}{T}=1\frac{T'}{T}.$$

The isothermal line is that indicating the relation between the pressure and volume of a gas due to expansion or compression at constant temperature.

The adiabatic line is that showing the relation between the pressure and volume of a gas due to expansion or compression when no transmission of heat takes place. No heat is extracted or added during the change of volume of the gas.

Where γ = ratio of the specific heat of gas at constant temperature and pressure.

The pressures at different points in the adiabatic curve are related by the equation

$$pv^{\gamma}=\text{constant}.$$

According to Rankine,

$$\gamma=1.408 \text{ for air.}$$

For hot surface (constant volume) engines

$$\gamma=1.30 \text{ to } 1.35.$$

For Diesel engines (constant pressure)

$$\gamma = 1.33 \text{ to } 1.41.$$

A vapor mixture or gas can be heated at constant pressure with the volume varying, the *specific heat* then being the amount of heat necessary to raise the temperature of 1 pound of the gas 1°, the pressure remaining constant; or the gas can be heated at constant volume, the pressure altering, and in that case the *specific heat* is the amount of heat necessary to increase the temperature of 1 pound of the gas 1°, the volume remaining constant.

The air standard diagram first used by Sir Dugald Clerk indicates the actual physical properties of the working fluid but neglects heat losses to cylinder walls. It represents ideal performance, which in the real engine may be approached but never attained. The relative perfection of an engine may be gaged by the closeness with which it approaches this ideal. As the Carnot cycle would represent the ideal efficiency of a heat engine and the Rankine cycle that in steam practice, so the air standard cycle serves the same purpose with the internal-combustion engine. This cycle assumes that gases obey the laws of Charles and Boyle within practical limits, that combustion is complete and takes place instantaneously with the piston at the inner dead center and that the gases are always in thermal and chemical equilibrium.

Compression cycles classified by Clerk are for engines operating with adiabatic compression and expansion (*a*) constant temperature, (*b*) constant pressure, (*c*) constant volume. In *a* adiabatic compression raises the temperature through the entire range, the total heat is received during isothermal expansion at the upper temperature. Adiabatic expansion reduces the working fluid from the upper to the lower temperature. The heat discharged is rejected by isothermal compression at the lower temperature. This constitutes the Carnot cycle. In *b*, constant pressure, adiabatic compression raises the pressure from the lower to the higher limit, and the heat is added at the upper constant pressure and increasing temperature. Adiabatic expansion reduces the working fluid from the upper to the lower constant pressure, the heat discharged is rejected at the lower constant pressure and diminishing temperature. In *c*, constant volume, adiabatic compression raises the temperature through a certain range. Heat is supplied above that range at constant volume so that both pressure and temperature then increase. Adiabatic expansion reduces the temperature through a certain range and increases the volume to that existing before compression. Heat discharged is rejected at constant volume and diminishing temperature.

Where t = temperature before compression;
v = volume before compression;
t_c = temperature after adiabatic compression;
v_c = volume after adiabatic compression;
E = thermal efficiency,

$$E = 1 - \frac{t}{t_c},$$

and it can be shown that $\left(\frac{v_c}{v}\right)^{\gamma-1} = \frac{t}{t_c}$,

$$E = 1 - \left(\frac{v_c}{v}\right)^{\gamma-1},$$

and if $\frac{v_c}{v} = \frac{1}{r}$ . . . the compression ratio,

$$E = 1 - \left(\frac{1}{r}\right)^{\gamma-1}.$$

Thus the thermal efficiency depends only on the ratio of the maximum volume before compression to the volume after compression. The constant pressure and constant volume are the best cycles for maximum efficiency and maximum power for given stresses in which sufficient compression followed by effective expansion is an essential feature. Without adiabatic compression such expansion is very limited. Compression before ignition in the internal-combustion engine extends the range of effective expansion.

Heat losses in internal-combustion engines are as follows:

(*a*) Loss through the walls externally cooled when gases are at maximum temperature and during expansion. (*b*) Throttling of air inlet and back pressure during exhaust. (*c*) Incomplete combustion at maximum temperature and loss through exhaust. (*d*) Varying specific heat increasing with rise in temperature.

The efficiency of an engine, where H is the total heat taken in by the engine, and H' is the heat discharged after performing work, the portion disappearing in work being $H-H'$ and with no other heat loss, would be

$$E=\frac{H-H'}{H}.$$

In Fig. 2 where expansion is such as to allow the heat to be discharged with the volume similar to that existing before compression, the heat supplied to the cycle is

$$H=K_v(T-t_c),$$

heat discharged is

$$H'=K_v(T'-t),$$

efficiency is

$$E=\frac{K_vT-t_c-K_c(T'-t)}{K_v(T-t_c)},$$

$$E=1-\frac{T'-t}{T-t_c}.$$

Both curves are adiabatic and pass through similar volumes

$$\frac{T'}{T}=\frac{t}{t_c},$$

so that

$$\frac{T'-t}{T-t_c}=\frac{T'}{T}=\frac{t}{t_c}.$$

The efficiency may therefore be expressed,

$$E=1-\frac{T'}{T} \text{ or } 1-\frac{t}{t_c}.$$

In the constant pressure type Fig. 3, the compression pressure is raised from p at b to p_c at d. Fuel is injected from d to e.

When K_p = Specific heat at constant pressure;
K_v = Specific heat at constant volume;
G_1 = Heat supplied during period $d\,e$;
G_2 = Heat rejected during period $e\,c$.

Then $G_1 = K_p(T - t_c)$,

$G_2 = K_v(T - t)$,

$$E = \frac{K_p(T - t_c) - K_v(T_1 - t)}{K_p(T - t_c)}.$$

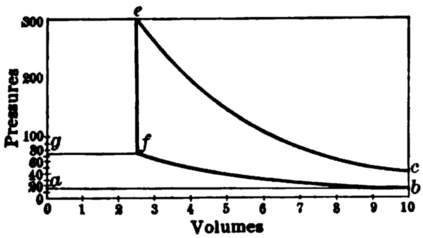


FIG. 2.—Pressure-volume diagram (constant volume).

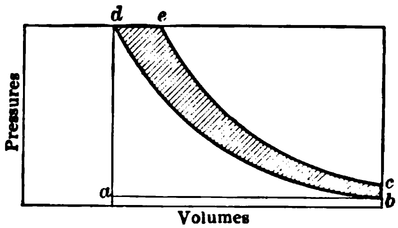


FIG. 3.—Pressure-volume diagram (constant pressure).

FIG. 2.

Temperatures	*Pressures*	*Volumes*
t absolute temperature at b	p absolute pressures at b	v_0 volume at b
t_c absolute temperature at f	p_c absolute pressures at f	v volume at c
T absolute temperature at e	P_0 absolute pressures at e	v_c volume at f
T' absolute temperature at c		

FIG. 3.

Temperatures	*Pressures*	*Volumes*
t absolute temperature at b	p absolute pressure at b	v_t volume at b
t_c absolute temperature at d	p_c absolute pressure at d	v_e volume at c
T absolute temperature at e		v_f volume at e
T_1 absolute temperature at c		

The specific heat of gases increases rapidly with the temperature. Sir Dugald Clerk gives the following figures in Table 2 founded on results he obtained with an experimental engine as the apparent instantaneous specific heats in foot-pounds per cubic foot of working fluid at 0° C. and 760 mm. pressure.

TABLE 2

CLERK

Temperature	Specific heat at constant volume	Temperature	Specific heat at constant volume
° C.	Foot-pounds	° C.	Foot-pounds
0	19.6	800	26.2
100	20.9	900	26.6
200	22.0	1000	26.8
300	23.0	1100	27.
400	23.9	1200	27.2
500	24.8	1300	27.3
600	25.2	1400	27.35
700	25.7	1500	27.45

Mean Specific Heats

0–100	20.3	0–900	23.9
0–200	20.9	0–1000	24.1
0–300	21.4	0–1100	24.4
0–400	21.9	0–1200	24.6
0–500	22.4	0–1300	24.8
0–600	22.8	0–1400	25.0
0–700	23.2	0–1500	25.2
0–800	23.6		

Methods of operation.—Petroleum engines operate either with " constant volume," having the various processes of that cycle performed as shown in Fig. 4, or they operate at " constant pressure " with the periods of the cycle as indicated in Fig. 5. Examples of the former type are found in gasoline engines and some makes of oil engines while the latter is exemplified in the Diesel engine.

Cycles of operation.—Practically all engines of this type operate on either: (*a*) the four-cycle (four-stroke cycle, Otto cycle, or Beau de Rochas cycle), or (*b*) on the two-

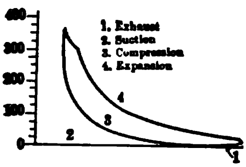


FIG. 4.—Constant volume diagram with various processes. 1. Exhaust. 2. Air inlet. 3. Compression. 4. Expansion.

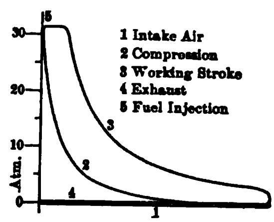


FIG. 5.—Constant-pressure diagram with various processes.

cycle plan (two-stroke cycle). With the former, two revolutions or four strokes of the piston, viz.: (1) air inlet, (2) compression, (3) expansion, (4) exhaust, form the complete cycle as shown in Figs. 4 and 5. With the two-cycle type these four processes are performed in one revolution or two strokes of the piston, viz., first stroke expansion (the compression stroke having just been completed), at the end of which stroke the piston uncovers the exhaust ports in the cylinder walls through which the burnt gases escape. A current of pure air at a slight pressure enters the cylinder at this period and thus it becomes scavenged of the exhaust gases. During the second or inward stroke of the piston compression takes place (after the piston has passed the exhaust ports thus closing them); fuel also enters during the end of this period. Ignition of the explosive mixture then occurs and the piston is impelled forward again, commencing another cycle.

Four-cycle advantages.—The smaller petroleum engine (the larger Diesel engines are explained later separately) has the following advantages: (*a*) lower fuel consumption (see table of tests, page 583), (*b*) more complete combustion of fuel, (*c*) simplicity of construction, the crankcase being open and moving parts accessible or in view, (*e*) use of lowest grades of crude or fuel oil without the tendency to carbonization on piston or piston rings and exhaust passages.

Two-cycle advantages.—(*a*) Absence of exhaust and air-inlet valves and valve

motion necessary with the four-cycle type, (*b*) power of piston displacement developed per unit of volume as compared with four-cycle type, being 75 to 90 per cent greater, (*c*) more even crank effort, (*d*) lighter flywheel than with four-cycle type.

Disadvantages.—With the four-cycle type: (*a*) variable crank-pin effort necessitating heavy flywheel, (*b*) greater total weight per H.P. of engine, (*c*) necessity of exhaust and air valves and valve motion. With the two-cycle type: (*a*) inferior combustion of fuel and smoky exhaust gases, (*b*) greater lubrication required and more cooling water necessary, (*c*) increased fuel consumption, (*d*) possible leakage of air when compressed in crankcase.

(For comparison of two- and four-cycle Diesel engines see page 561.)

Thermal efficiency.—The ratio of the heat utilized (that is, the equivalent of the heat shown on the actual or Brake H.P. developed) as compared with the total heat units contained in the fuel consumed is known as the thermal efficiency of an engine and here referred to as the "effective thermal efficiency."

Mechanical efficiency.—Mechanical efficiency is the ratio between the actual or Brake H.P. as shown to be developed by the brake or other similar device for measuring the power developed, and the total or gross power obtained as shown by the indicator diagram.

Volumetric efficiency.—Volumetric efficiency is the ratio between the weight of air contained in the cylinder of a four-cycle engine when the compression stroke begins and that of the air required to fill the same volume with air at atmospheric pressure. In a two-cycle engine the percentage of pure air present in the total weight of gas or burnt products filling the cylinder at the commencement of compression must also be taken into account.

Indicated H.P.—Indicated H.P. is that calculated from the indicator card as follows:

$$\frac{PLAE}{33{,}000},$$

when P = Mean effective pressure;
L = Length of stroke in feet;
A = Area of piston in square inches;
E = Number of impulses per minute.

Brake or actual H.P. is the power developed as measured at the crankshaft or flywheel of the engine by Prony brake or water dynamometer and is found as follows:

$$\text{B.H.P.} = \frac{2R\times\pi\times l\times Q\times n}{33{,}000},$$

where R = Radius of wheel in feet;
Q = Weight in pounds on scale + weight of brake;
l = Distance in feet from center of shaft to point of contact of lever with scale;
π = 3.1416;
n = R.P.M.

(Methods of testing are described on page 547.)

Vaporizers and sprayers.—The vaporizers (hot bulbs or hot surfaces) and the various oil-spraying devices are the two most important and interesting parts of the hot-surface type oil engine. They are peculiar to this design and it is only necessary to note how numerous have been the different detailed constructions of these two parts in the different makes of engines, both in this country and in Europe, to realise how large an amount of study and inventiveness has been bestowed on them alone. Sectional illustrations of this type of engine indicate the relative position of the vaporiser and

sprayers with regard to the cylinder, air and exhaust valves and other parts. Fig. 6 to Fig. 24 show the vaporizers, and in Fig. 32 to Fig. 35 are shown different oil-spraying devices.

Four-cycle horizontal stationary engines.—1. The Hornsby-Akroyd (English) type of 1896 is shown in Fig. 6. The compression pressure there used was 40 pounds, the mean effective pressure 31.8 pounds, the fuel consumption was 0.99 pound per B.H.P. per hour, and the thermal efficiency 14 per cent. The engine was started by a heating lamp placed beneath the vaporizer and built in sizes 4 to 100 H.P. in one cylinder.

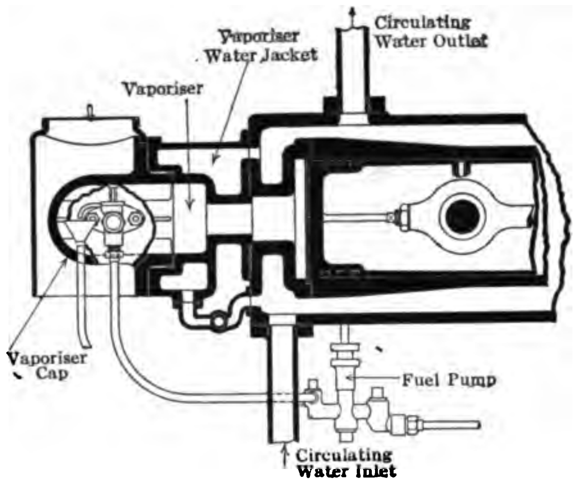


Fig. 6.—Hornsby-Akroyd type vaporizer, 1896.

2. **The Ruston & Proctor** (English) 1909 type is that seen in Fig. 7. This engine operated with a compression pressure of 280 pounds, the fuel economy was .45 pound, thermal efficiency 31 per cent and the M.E.P. 78 pounds. The engine was started by means of a heating lamp; the fuel was injected at the end of the compression stroke and a water jet was allowed to enter the vaporizer to maintain its proper temperature, especially with heavy loads. It was built in sizes of 10 to 85 H.P. in one cylinder.

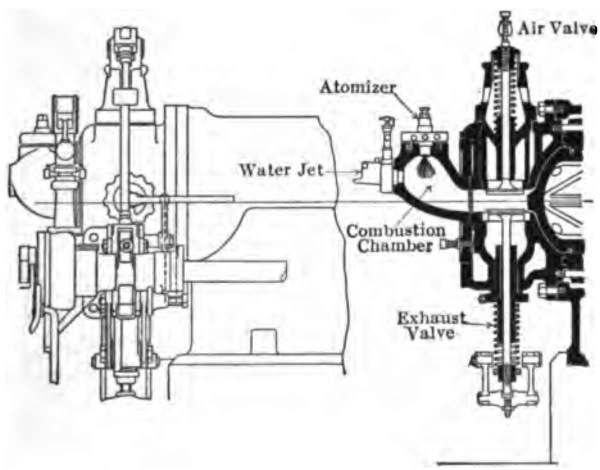


Fig. 7.—Ruston & Proctor vaporizer, 1909.

3. **The De La Vergne "DH" type** (U. S. A.) was first built about 1912 and is shown in Fig. 8. The compression pressure was 195 pounds, the fuel economy .5 pound, fuel injection at the end of compression stroke, thermal efficiency 30 per cent. It was built in sizes of 40 to 65 H.P. in one cylinder.

4. **The Crossley (English) Modern Engine** is shown in Fig. 9. The compression of approximately 400 pounds alone causes ignition in the larger sizes; in the smaller sizes a tube heated externally before starting is used to supplement the heat of compression. With 117 B.H.P., 18½ inch dia. × 28 inches stroke and 180 R.P.M., the thermal efficiency was 32.2 per cent, fuel economy .427 pound.

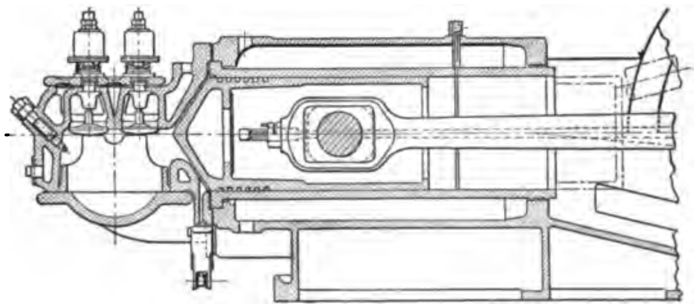


Fig. 8.—De La Vergne D. H. type.

The fuel consumption of the Crossley Oil Engine at various loads is shown on the diagrams in Fig. 10.

5. **The De La Vergne "FH" type** (U. S. A.) was first built in 1908 and is shown in Fig. 11. This design has air blast at about 800 pounds pressure injected into the vaporizing chamber with the fuel. Any grade of crude or fuel oil is used in this type,

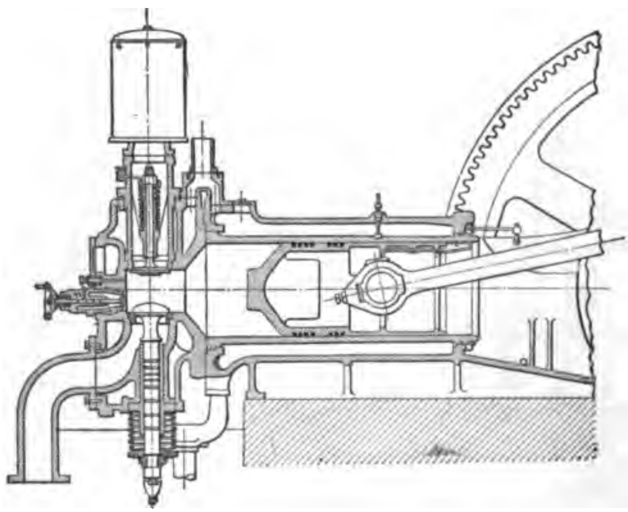


Fig. 9.—Crossley modern oil engine.

which is made possible in a large measure by the relative location of the air and exhaust valves and the hot vaporizing chamber, resulting in a partial scavenging effect which expels through the exhaust sand or particles not capable of complete combustion found in some of the lower grade crude oils. The compression pressure is 275 pounds, the fuel economy .45–.50 pound per B.H.P. hour, thermal efficiency 31 per cent; the fuel is injected at the end of the compression stroke. The injection air is compressed in a

small two-stage compressor operated by an eccentric from the crankshaft. This type is built from 100 to 150 B.H.P. in one cylinder.

6. The Blackstone (English) vaporizing arrangement is shown in Fig. 12. There

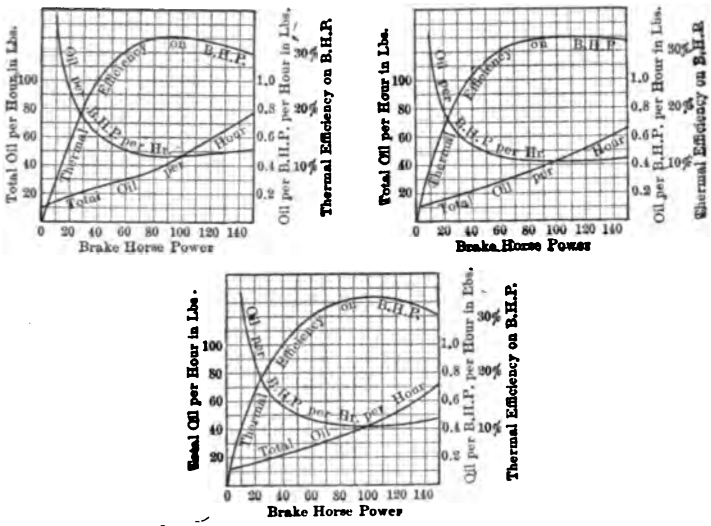


Fig. 10.—Crossley fuel consumption curves.

are two fuel injection valves in this design. One injector is arranged to impel the spray into the hot bulb at all ranges of loads (thus at light load sufficient temperature is maintained to cause ignition); the second injector allows the spray to enter directly into the

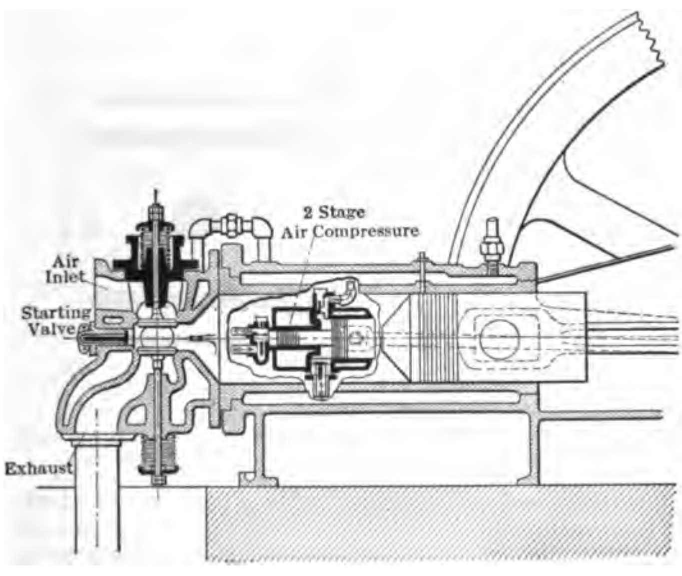


Fig. 11.—De La Vergne F. H. type.

combustion space and only injects fuel when the engine is carrying a load. This engine operates with 150 pounds compression pressure and maximum initial pressure of 300

pounds. Air at about 450 pounds is injected with the fuel, the M.E.P. is approximately 80 pounds, fuel consumption of 0.465 pound. The injection air is compressed in a small two-stage compressor actuated from the crankshaft.

7. **The Hornsby 1915 " R " type** vaporizer with water-jacketed chamber at its back

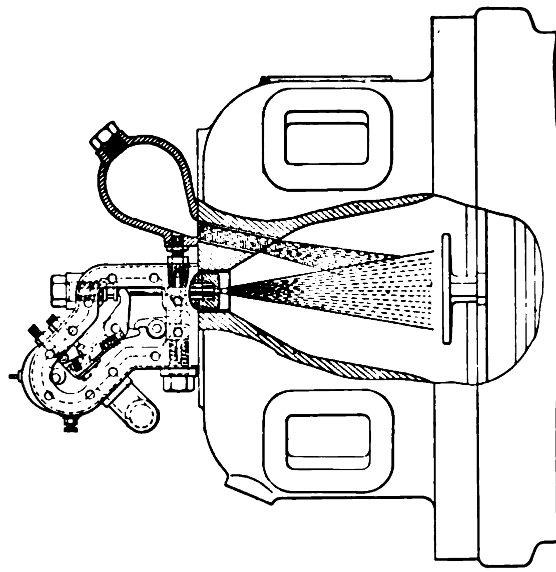


Fig. 12.—Blackstone vaporizer.

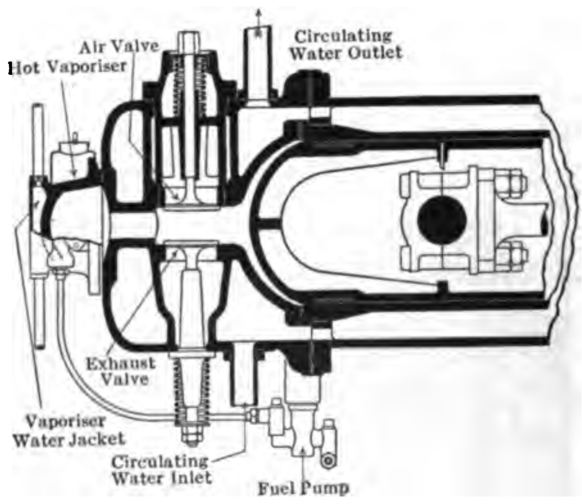


Fig. 13.—Hornsby 1915 Type "R."

end is shown in Fig. 13. It is made in the larger sizes up to 180 H.P. in one cylinder. Compression pressure is about 265 pounds, fuel consumption 0.47 pound per B.H.P. hour, M.E.P. 61.5 pounds, thermal efficiency 28.7 per cent. Injection of fuel is at the end of the compression stroke. It is started with a heating lamp.

8. The Ruston Modern high compression engine with solid injection of fuel is shown in Fig. 14. It starts cold without heating lamp and has solid fuel injection (that is, without air blast). It operates with about 430 pounds compression and has M.E.P. of 85 pounds. The fuel consumption is 0.4 pound per B.H.P. hour and thermal efficiency 35 per cent. It is built in sizes up to 120 H.P. in one cylinder.

Fuel consumption of the Ruston & Hornsby engine at various loads is shown in Fig. 15 and the comparative results on a Willans & Robinson Diesel engine are shown in Fig. 16.

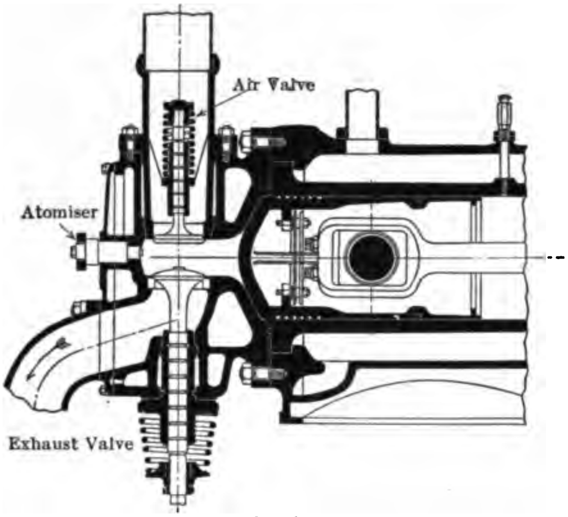


FIG. 14.—Ruston modern high-compression type.

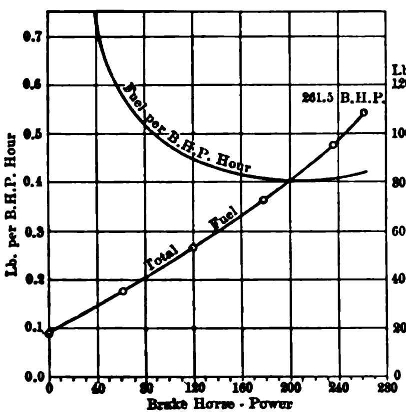


FIG. 15.—Ruston & Hornsby fuel consumption curves.

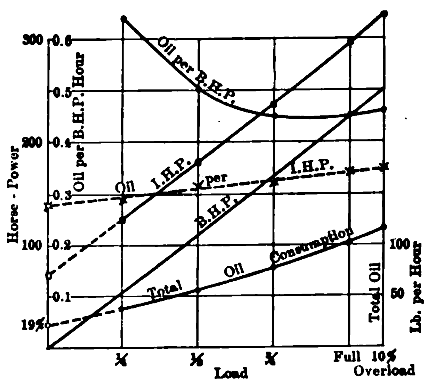


FIG. 16.—Willans & Robinson Diesel fuel consumption curve.

9. The De La Vergne "SI" (solid injection) type is shown in Fig. 17. This engine is the most recent design of this builder, the patented features being (*a*) the method of injecting fuel which is sprayed into the combustion space at high pressure (about 2000 pounds), without air blast, (*b*) the use of two sprayers placed opposite each other at opposite sides of the combustion space and so arranged that the two sprays meet each other in the center of this space, thus becoming thoroughly pulverized. The

particles of oil are well distributed throughout the whole combustion space and the employment of compression pressure at about 350 pounds causes sufficient temperature to ignite the intimately mixed vapor and air. The fuel consumption is 0.42 pound. In some tests fuel consumption as low as 0.38 pound per B.H.P. hour has been recorded. This engine is built in sizes of 100 to 150 H.P. in one cylinder.

Remarks.—The reference to the above designs (1 to 9) and the illustrations Fig. 6 to Fig. 17 include representative horizontal slow and medium-speed four-cycle petroleum engines of heavy construction (about 400 pounds per B.H.P.). These designs are shown as the information concerning them was most available. To refer to all the successful petroleum engines built here and in Europe would occupy greater space than is available in this chapter. It will be evident that the older hot-surface types of oil engines, while admittedly inefficient, were very simple in construction as built in the nineteenth century. They have been superseded by the modern (1920) oil engine

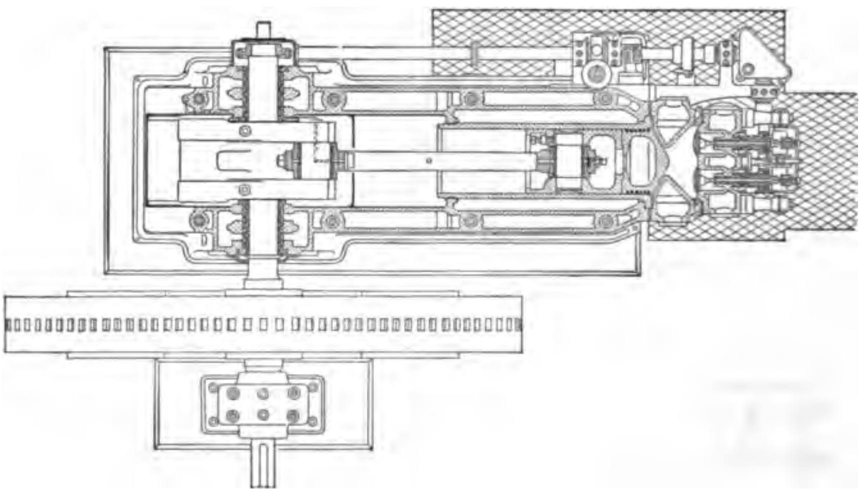


FIG. 17.—De La Vergne S. I. type.

of that class which has proved to have an effective thermal efficiency of 30 to 35 per cent (calculated on the effective, actual or B.H.P.) as compared with the former efficiency of 14 to 18 per cent. They are even simpler in construction than former types and with proper care and intelligent operation are the equal of any other prime mover in continuous operation. The increased thermal efficiency is largely due to: (*a*) higher compression pressures, (*b*) improved spraying or pulverizing of the fuel as it enters the combustion space. The pressure of 40 pounds compression in 1893 with thermal efficiency of 14 per cent has been increased in the modern (1920) engine to from 175 to 450 pounds compression and 30 to 35 per cent thermal efficiency. In the earlier engines the fuel was injected during the air suction period and entered a heated chamber, and only that pressure of compression was then allowable which would not cause pre-ignition of the mixture before the piston reached the inner dead center. In the modern engines (and since 1906 when the Diesel patents lapsed) the period of the injection of fuel peculiar to the Diesel principle, viz., at the end of the compression stroke, has been adopted by most makers of " hot-surface type " engines. The period of injection of the fuel being thus practically simultaneous with that of ignition, the pressure of compression can be carried to a much higher degree, as seen in the De La Vergne " FH "

and " DH " types, the Blackstone or the Crossley designs, without the danger of pre-ignition, as air only fills the cylinder during the period of compression.

In some designs, such as the Ruston, De La Vergne " SI," etc., the pressure of compression is carried still higher or to about 375 to 450 pounds, and the injection of the fuel being " solid," that is, without the accompanying air blast usual with many Diesel engines, the cooling effect consequent on the expansion of the injection air from 1200 pounds down to from 400 to 500 pounds, when entering the combustion space, is eliminated. Accordingly sufficient temperature is developed to cause ignition at starting when the engine cylinder and other parts are cold, and the heated vaporizer hot surface, hot plate, or other device formerly used to furnish heat necessary to raise the air when compressed to the lower level of 40 to 150 pounds has been eliminated. Thus many of the designs of " hot surface " oil engines which have been very much simplified and embrace these two features peculiar to the true Diesel type might even be classified as Diesel engines.

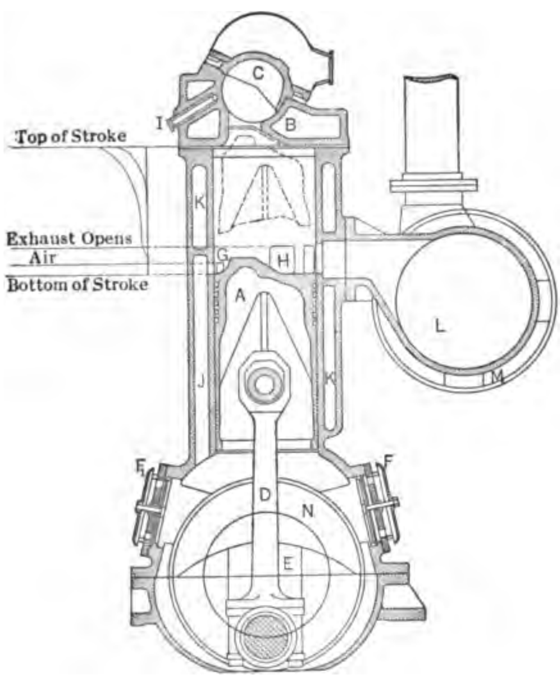


FIG. 18.—Beardmore two-cycle type. (*A*) Piston. (*B*) Cylinder cover. (*C*) Combustion chamber. (*D*) Connecting rod. (*E*) Crank. (*F*) Air inlet valves. (*G*) Scavenging air ports. (*H*) Exhaust ports. (*I*) Fuel injection nozzle. (*J*) Scavenging air passage. (*K*) Water jacket. (*L*) Exhaust silencer. (*M*) Water jacket. (*N*) Balance weight.

Two-cycle stationary, vertical and horizontal.—The vertical two-cycle oil engine in which the process of compression of the air to about 4 to 8 pounds is effected in the crankcase is exemplified by the illustrations, Figs. 18 to 21, showing in section representative types. Fig. 18 illustrates the Beardmore (English); Fig. 19 the Fairbanks Morse (U. S. A.); Fig. 20 the Bolinder, (Swedish) and Fig. 21 illustrates the Petter (English) engine. These types are built in varying sizes from about 5 to 300 H.P. The chief feature of such two-cycle engines is their simplicity of construction. The piston opens and closes the ports in the walls of the cylinders controlling the air inlet and the exhaust of the burnt products of combustion. Air inlet and exhaust valves and all valve motions are eliminated. The hot surface, varying in design in different engines, is heated before starting by an external lamp. The necessary temperature to cause ignition is maintained afterwards while in operation by the burning of the fuel within or against its surfaces. Compression takes place in the crank chamber, and therefore a greater pressure than atmospheric obtains within that chamber during this process. Care has to be exercised to prevent leakage of air between the journals and the bearings. Special bearing designs, such as those made to include the stuffing box around the crank shaft at each outer main bearing, are provided. The two-cycle type, simpler in construction

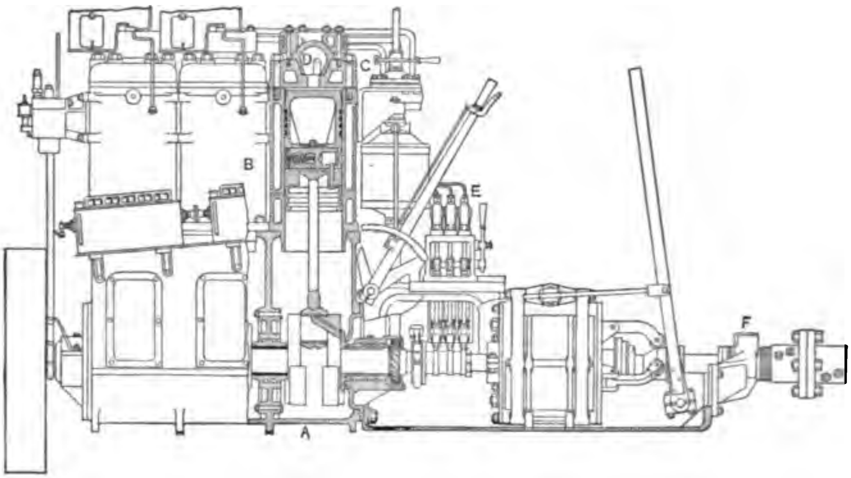


Fig. 19.—Fairbanks Morse two-cycle type. (*A*) Engine frame. (*B*) Cylinder. (*C*) Cylinder head. (*D*) Vaporizer. (*E*) Fuel-supply pumps. (*F*) Thrust block.

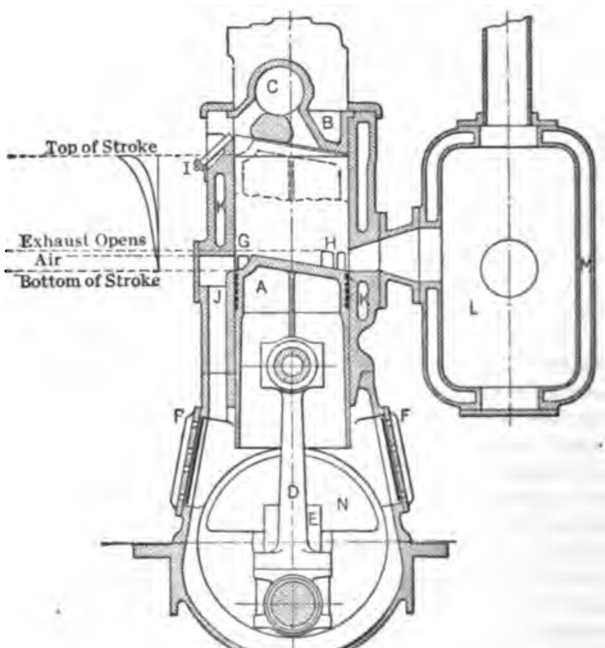


Fig. 20.—(*A*) Piston. (*B*) Cylinder cover. (*C*) Combustion chamber. (*D*) Connecting rod. (*E*) Crank. (*F*) Air inlet valves. (*G*) Scavenging air ports. (*H*) Exhaust ports. (*I*) Fuel injection nozzle. (*J*) Scavenging air passage. (*K*) Water jacket. (*L*) Exhaust silencer. (*M*) Water jacket. (*N*) Balance weight.

and, having an impulse at each revolution of the crank pin instead of at the end of each two revolutions, as in the four-cycle, is approximately 30 per cent lighter in construction and requires a much lighter flywheel; yet, for continuous heavy duty, experience shows that the four-cycle type is preferred. The horizontal stationary two-cycle oil engine may be exemplified by the sectional views Fig. 22 to Fig. 24.

The Bessemer horizontal two-stroke cycle engine (Fig. 22) is built with single cylinders from 15 to 85 H.P. The air is taken in through the main frame casting, and passes through a Corliss type valve, shown in sectional view. It is actuated from an eccentric on the crankshaft. Cooling water is arranged to pass under the crankcase and the bottom crosshead guide and thence to the cylinder water jacket. This arrangement cools the lubricant in the crankcase which lubricates the main bearings, connecting rod, crosshead and wrist pin bearings.

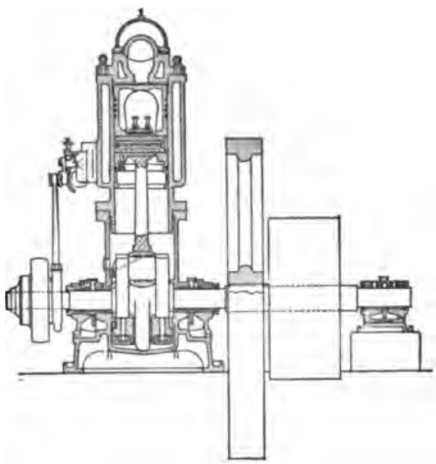


Fig. 21.—Petter two-cycle type.

The vaporizer casting in the cylinder head gives the necessary clearance for the low compression used and permits the location of the spray valve in such a position as to inject the fuel oil directly up against an uncooled part of the vaporizer which is heated

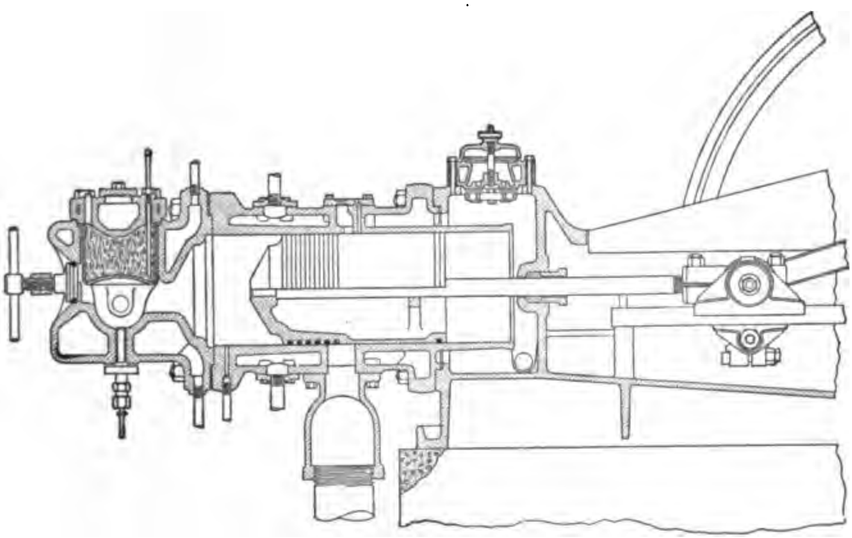


Fig. 22.—Bessemer two-cycle type.

before starting by a blast lamp. The governor is arranged to give a variable pump stroke, and the engine speed is further regulated by an auxiliary cam-actuated linkage connected to the governor and holding the pump suction valve open except for

a variable period of 12° to 16° of the crank angle, during which the valve closes suddenly and fuel is injected into the combustion chamber.

In the smaller size engines the combustion chamber is made of steel forgings and contains approximately three pounds of mercury which is completely sealed in the interior of the vaporizer. The object of the mercury is to maintain constant vaporizer temperature irrespective of the load on the engine.

The fuel economy of the Bessemer engine varies according to the cylinder size: At full load from 0.65 to 0.9 pound, at three-quarters load from 0.7 to 1.0 pound, at half load from 0.8 to 1.2 pounds. Cylinder dimensions range from 8½ by 15 inches to 16 by 20 inches stroke. Engine speed ranges from 275 to 250 R.P.M. The weight of the engine per brake horse-power for single cylinder units ranges from 390 to 275

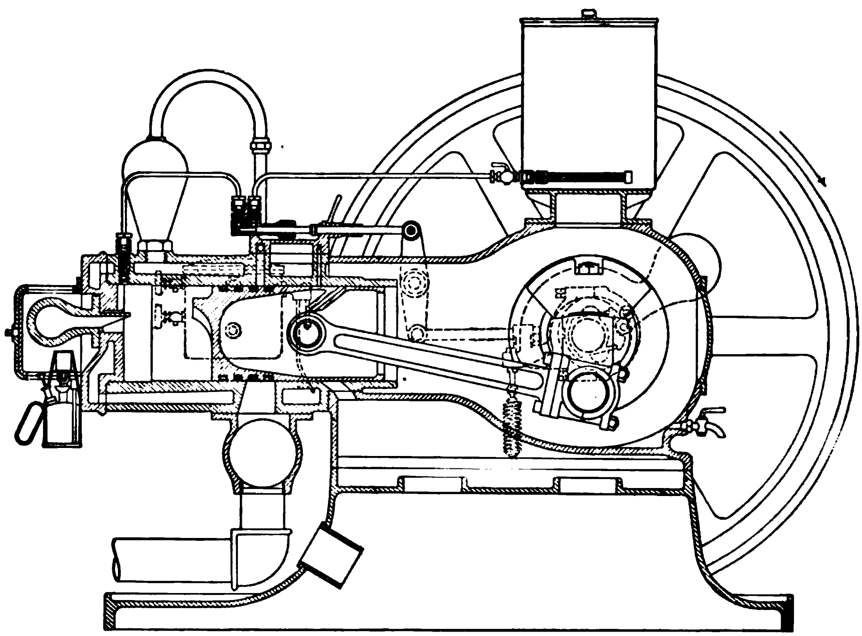


FIG. 23.—Mietz two-cycle type.

pounds. The Mietz two-cycle engine, shown in Fig. 23, has crankcase compression similar to the vertical type described above. In this engine steam from the cylinder jacket (which is allowed to operate at a temperature above the boiling point) enters the combustion space with the fuel.

The Buckeye two-cycle low-compression horizontal oil engine is illustrated in Fig. 24. Air for scavenging enters through openings in the front end of the crankcase, passes under the frame through ports and intake plate valves on the engine side near the crosshead, then into the combustion space behind the piston. A box-shaped volume in the lower part of the frame and connected to the above space is proportioned to give a scavenging air pressure of about 3 pounds per square inch. The trunk piston has a length sufficient to insure that the inlet and exhaust ports are closed on the inner dead center. A piston rod connects the crosshead, passing through a stuffing box which seals the scavenging air space in front of the piston. The crosshead and crank pin bearings work in an enclosed crankcase permitting splash lubrication for these parts. The

cylinder jacket and liner constitute an integral casting, the two being connected by walls forming the intake and exhaust ports and by a flange at the head end through which are the openings for the passage of cooling water into the cylinder head. Cooling water is admitted to the jacket at a point near the exhaust port. Only that section of the cylinder reaching from the above ports toward the head end is water-jacketed. The cylinder extends back to a flange which is secured to the main frame by studs.

A simple check-valve type-spray valve injects oil into the center of a cup-shaped uncooled vaporizer. For starting, the latter is heated by a lamp.

For most sizes using distillate oils of about 30° Bé., having lower heat content

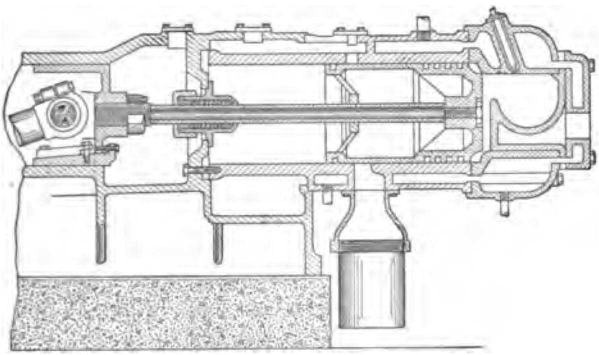


FIG. 24.—Buckeye two-cycle type.

of approximately 18,500 B.t.u., the fuel consumption is as follows under ordinary operating conditions:

Full load: 0.65–0.7 pound per B.H.P. hour;
$\frac{3}{4}$ load: 0.70–0.75 pound per B.H.P. hour;
$\frac{1}{2}$ load: 0.80–0.90 pound per B.H.P. hour.

The engine weight per B.H.P. varies from 270 to 320 pounds, depending on size, arrangement of cylinders and speed. Lubrication of parts other than the crank pin, wrist pin and crosshead bearing surface is from a mechanical forced-feed lubricator. Engine speed is controlled by a simple governor which acts on a by-pass valve in the discharge side of the fuel supply pump.

The Worthington two-cycle Diesel solid injection engine is shown in section at Fig. 25 and Fig. 26. It is made with one, two and four cylinders and in sizes from 25 to 240 H.P. In the base of the engine, back of the crosshead guides, are two air receivers used as reservoirs for scavenging air. By this arrangement the crankcase is relieved of air pressure and no sealing precautions at crankcase joints and bearings are necessary. The air is admitted in such a way as to avoid dust and dirt being drawn into the crankcase or the power cylinder. Feather valves are used for the air-inlet suction valves.

In starting, a unique igniter is employed to produce the first ignition when the jacket water is cold. This consists of a simple paper cartridge, easily inserted and positive in action. The glowing of the burning cartridge ignites the initial charge in the same manner as a hot plate starts a match burning. Provision has been made for accessibility to the working parts by placing large cover plates on the crankcase, hand-hole plates on intermediate heads between the power cylinder and the crankcase, and at other points. Hand-hole plates at various points in the water jackets of the cylinders allow jackets to be readily freed from scale. A similar provision is made in the design of the head, which is in two parts.

Classification.—Hot-surface oil engines should be divided into two classes, low- and high-pressure types. The former is exemplified by the Mietz or the Petter in the two-cycle type and by the De La Vergne " DH " type, or the Hornsby in the four-cycle design, where a compression pressure of 100 to 175 pounds is used, in contrast to the latter-named class (high-pressure type) exemplified in the Ruston, Crossley or De La Vergne " FH " or " SI " type, where compression pressures of 350 to 450 pounds are used and where ignition of the explosive mixture is caused by compression of the air alone, and where the fuel is injected after compression is nearly or entirely completed. Such engines operate practically at constant pressure and as far as stresses of working parts are concerned, are similar to the Diesel engine; and the design and construction

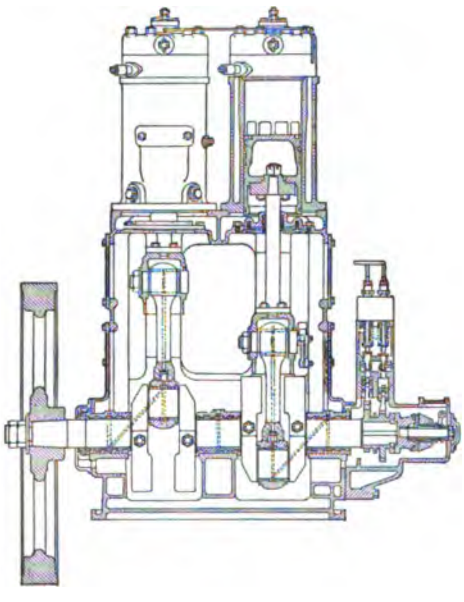


Fig. 25.—Worthington two-cycle vertical sectional view.

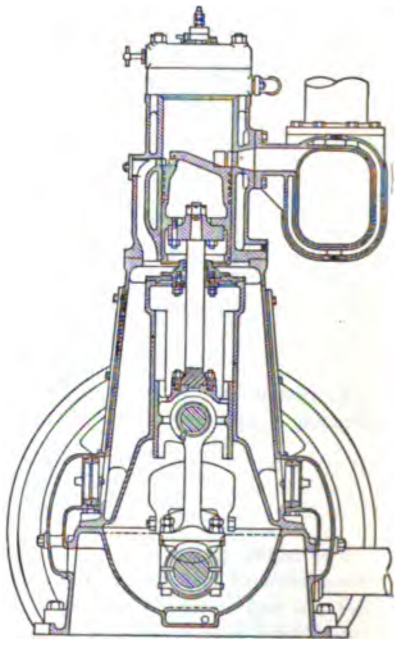


Fig. 26.—Worthington two-cycle vertical sectional view.

of their parts are calculated by, and practically subject to, the formulæ governing the Diesel engine outlined on pages 562–576.

The general design of the chief parts of the low-pressure hot-surface oil engine is governed by the following considerations.

Cylinder.—With nearly all leading makers the cylinder is made in two parts, the cylinder casing and liner as shown in Fig. 8, the liner being held in place bolted to the back end and held in position at the forward end by a rubber ring between it and the outer casing. Thus the liner is allowed to expand and contract lengthwise and retain its exact shape cylindrically, and the strains resulting from impulses are transmitted through the outer casing. The liner can then be made of a higher class material (close-grained hard cast iron) than is necessary for the casing, which in most designs is now made a part of the bed plate and therefore is a heavy casting. This design of cylinder also facilitates removal and the replacing of the liner, in after years if necessary. The thickness of the metal of the cylinder liner equals 0.08 diameter of bore at the back

end and is approximately 25 per cent lighter at forward end. The thickness of the metal of the cylinder casing may be designed in accordance with the formulæ for Diesel engines, page 562. Space for water circulation is made from 1 to 1½ inches deep and arranged to allow free and efficient circulation of the cooling water.

In the smaller engines, especially those of the two-cycle type, the cylinder and casing are cast in one piece as shown in Fig. 21.

Piston.—In engines of this class the trunk piston, as shown in Fig. 27, is used almost exclusively, as it performs the function of a crosshead as well as that of piston. Its length is such that the pressure on its sides is less than 25 pounds per square inch of

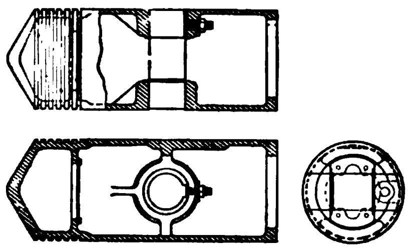


Fig. 27.—Trunk-piston hot surface.

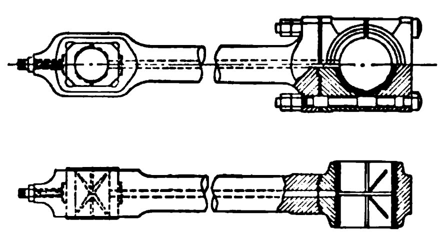


Fig. 28.—Connecting-rod hot surface.

rubbing surface. In order that proper lubrication may be easily maintained, and the wear consequent on the friction between piston and liner due to the angularity of the connecting rod be minimized, the length of piston should be 1.6 diameter.

Connecting rod.—The connecting rod, as shown in Fig. 28, when made of mild steel for slow-speed and medium-speed oil engines with trunk piston, is two and a half to three strokes in length. Its mean diameter X may be found as follows:*

$$X = 0.028\sqrt{Dl\sqrt{m}}$$

where D = Diameter of cylinder in inches;
l = Distance in inches between connecting rod centers;
m = Maximum or explosive pressure in pounds per square inch.

Connecting rod bolts should be made of the best and toughest wrought iron. A representative example is shown in Fig. 29. The cross-section of the connecting rod

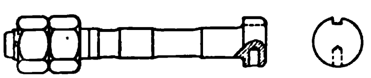


Fig. 29.—Connecting-rod bolt hot surface.

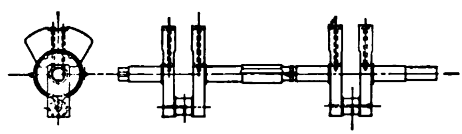


Fig. 30.—Crankshaft hot surface.

bolts at the bottom of their threads should be such in a four-cycle type that the stress as the suction stroke commences does not exceed 6000 pounds per square inch.

The stroke of this type varies in different designs. In high-speed engines the stroke is 1 to 1.3 diameter, while in slow-speed engines it is 1.3 to 1.6 diameter.

Piston speed should not exceed 900 feet per minute. With greater speed efficient lubrication is difficult and the wear of the cylinder liner may be greater, necessitating frequent reboring or renewals.

* An alternative formula is $d = .0164\sqrt[4]{mPl^2}$, when P = load on piston, d = diam. of rod and m = 30 with 200 ft. per min. piston speed, 20 with 400 ft., 15 with 600 ft. and 10 with 800 ft. per min. piston speed, l = conn. rod centers in inches.

Crankshafts for the smaller hot-surface low-pressure engines are usually made of the slab type (Fig. 30) and of one-piece steel forging. For high-pressure type hot-surface oil engines the description and formulæ for the Diesel engines referred to hereafter are equally applicable but in all cases the metal should be such as to fulfill the requirements of the specifications for Diesel crankshafts hereafter quoted. A "built-up" crankshaft similar to that shown at Fig. 56 is sometimes used in the larger engines. The following formula has proved satisfactory for low-pressure engines:

$$D=\sqrt[3]{\frac{S\times l}{120}},$$

where S = load on piston (area of cylinder in square inches × maximum pressure of combustion);
l = length of stroke in feet;
D = diameter of crankshaft at main bearing in inches.

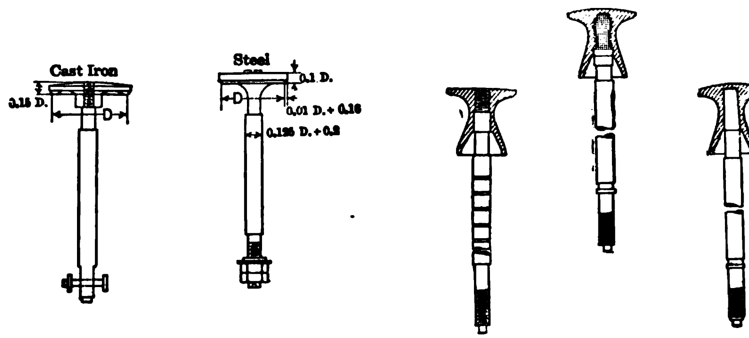


FIG. 31.—Air inlet and exhaust valves.

Pressure on bearings.—With main crankshaft bearings the maximum pressure should not exceed 400 pounds per square inch of projected area and on the crank pin this pressure should not exceed 500 pounds per square inch. Similarly, the piston or gudgeon pin should not be subjected to pressures exceeding 1800 to 2000 pounds.

Valves.—The air-inlet and exhaust valves are shown in Fig. 31 and their design can be calculated in a way similar to that with the valves of Diesel engines, the formulæ for which will be found in the description following.

The spraying device with the hot-surface type is a simpler apparatus than the pul-

FIG. 32.—Spraying devices for hot surface type.

verizers described and necessary for Diesel engines. The function of the sprayer is to vaporize or break up the particles or globules of the liquid fuel and distribute the vaporized spray or fog throughout the whole space of the combustion chamber or vaporizer so that the globules have the maximum amount of their surface exposed to the oxygen of the air into which they are sprayed. The small steel nozzle has a varying dimension from .020 to .060 inch. Representative spraying devices for engines of this type are shown in Fig. 32 and Figs. 33 and 34. With the larger hot-surface type oil engines and those having air blast injection similar sprayers or pulverizers are used as with Diesel engines described on pages 571–574.

The fuel sprayer as used on the De La Vergne " F. H." type where the air blast enters the combustion space with the fuel is shown in Fig. 35.

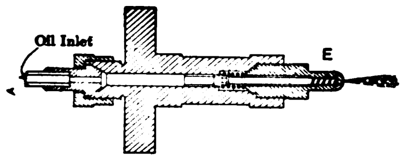


FIG. 33.—Spraying device for hot-surface type.

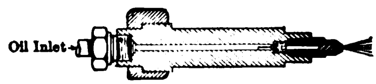


FIG. 34.—Spraying device for hot-surface type.

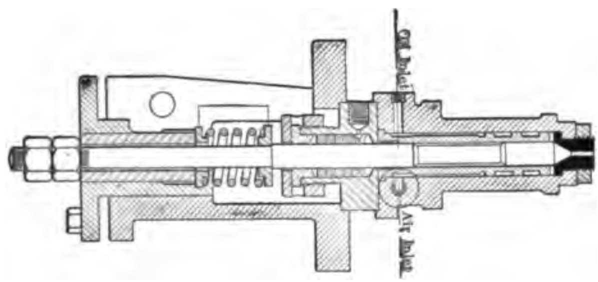


FIG. 35.—De La Vergne F. H. sprayer.

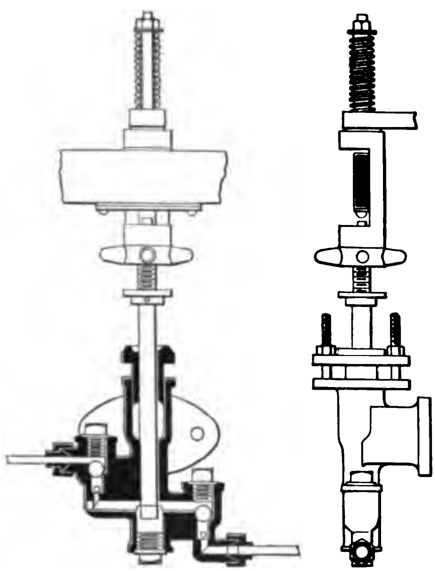


FIG. 36.—Oil supply pump.

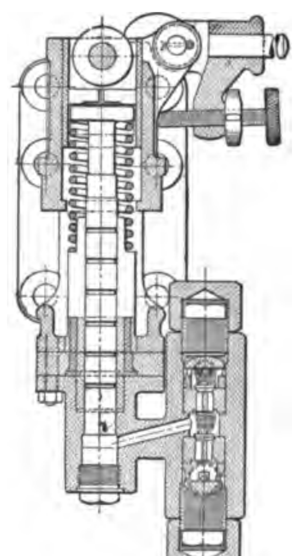


FIG. 37.—Oil supply pump, packingless type.

The oil pump, as shown in Fig. 36, is employed to raise the liquid fuel, after it has been properly strained of all impurities, to the sprayer, as high pressures are frequently developed in the connection between the oil pump and the sprayer. The pump body

and other parts are heavily designed and with a high factor of safety. Two suction and discharge valves are placed in the pump so as to insure proper functioning in continuous operation should grit or dirt be carried to them in the fuel.

A pump of modern design is shown in Fig. 37. It has no packing and is known as the "packingless" type. It is employed with the De La Vergne "D. H." engine and

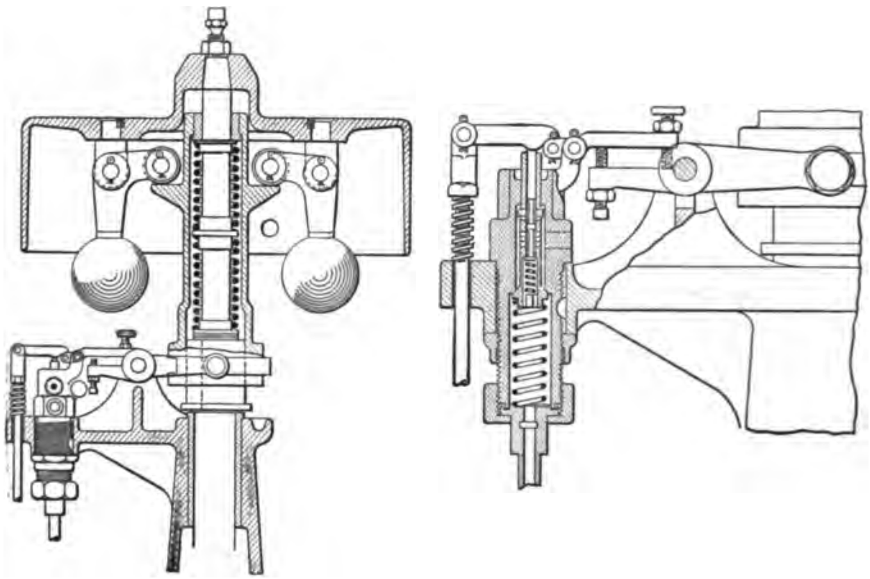


Fig 38.—Governing by-pass method.

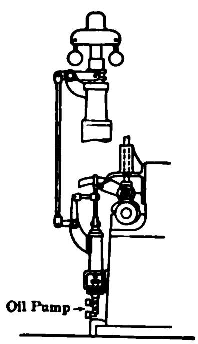


Fig. 39. Governing by varying pump stroke.

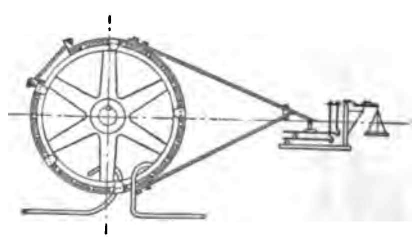


Fig. 40.—Prony brake.

also by other makers. The plunger is made an exact fit to the pump body and is grooved as shown.

The flywheel necessary to the two-cycle or four-cycle smaller hot-surface oil engine may be constructed in accordance with the formulæ given for the flywheels of Diesel engines.

Regulation of speed is effected by means of a pendulum governor arranged to vary the amount of fuel entering the vaporizer or combustion space in accordance with the load carried and to maintain an even speed of rotation of the crankshaft within the following limits: With fairly even load the speed variation should not exceed $1\frac{1}{2}$ per cent each side of the uniform speed of rotation; when the load is varied from full load to one quarter load the speed variation should not exceed 4 per cent and from full load to no load not over 5 per cent. There are two methods in operation. The governor either (*a*) by-passes the fuel not required through an overflow valve so that the correct

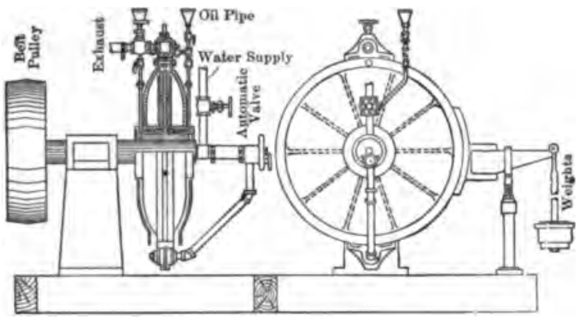


Fig. 41.—Water dynamometer.

amount required enters the vaporizer, or (*b*) lengthens or shortens the stroke of the pump furnishing the fuel as shown in Fig. 38 and Fig. 39.

Testing.—All engines of this description are tested at the factory before shipment. The objects of that test are, to ascertain (*a*) that the correct power is developed as specified in the maker's guarantee, (*b*) that the periods of opening and closing of the valves are properly timed and that the period of fuel injection is correct, (*c*) that the mechanical efficiency is standard, (*d*) that the fuel consumption does not exceed the guarantees. The method of testing is to attach to the smaller engines a Prony brake

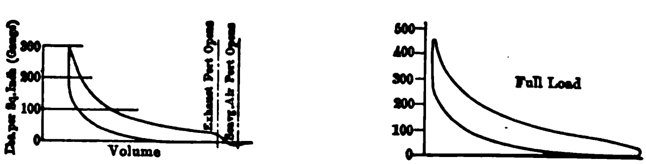
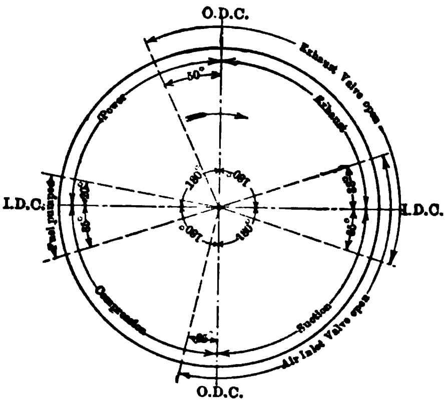


Fig. 42.—Representative indicator diagrams, two and four cycle.

and water-cooled pulley as shown in Fig. 40, and with the larger engines to attach a water dynamometer of the Froude design or a similar device as shown in Fig. 41. In addition a reducing motion is attached so that the length of the stroke of the engine piston is suitably reduced to suit the length of the diagram of the indicator. Then after the engine has been operated sufficiently to wear in the bearings to their seat and the piston has been worn in and the piston rings have become tight and without leakage, full load is applied by proper adjustment of the dynamometer. Indicator diagrams are recorded which show proper valve and fuel injection movements. Then the fuel consumption test is made by accurately measuring the amount consumed for one hour, during which period the load on the engine is recorded after each five or ten minute interval. Representative indicator diagrams from a two-cycle, and a four-cycle

oil engine are shown in Fig. 42. The timing of the valves is also shown in Fig. 43. If a test is required after the engine is installed and connected to the machinery to be



Two revolutions of crank pin.

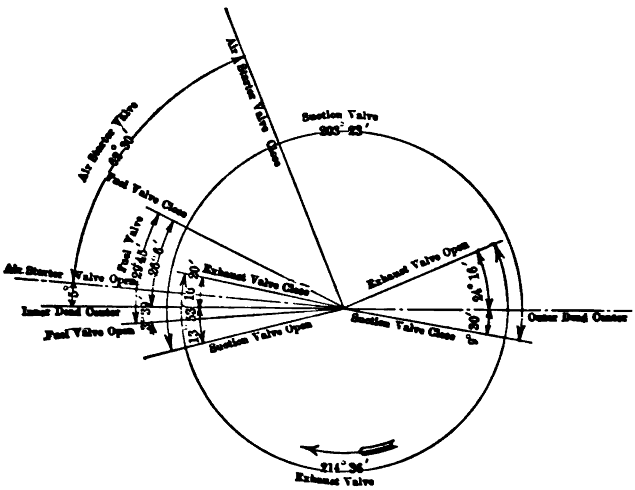


Fig. 43.—Valve movement diagrams.

operated it will be necessary to attach the apparatus as above outlined, if the test is to be made so that the exact performance of the engine can be computed.

RULES FOR CONDUCTING TESTS OF GAS AND OIL ENGINES [1]

Object and preparations.—Determine the object, take the dimensions, note the physical condition of the engine and its appurtenances, install the testing appliances, etc., and make preparations for the test accordingly.

Operating conditions.—Determine what the operating conditions should be to conform to the object in view, and see that they prevail throughout the trial.

Duration.—The test of a gas or oil engine with substantially constant load should be continued for such time as may be necessary to obtain a number of successive records

[1] Extracts from A. S. M. E. Code of tests.

covering periods of half an hour or less during which the results are found to be uniform. In such cases a duration of three to five hours is sufficient for all practical purposes.

Starting and stopping.—The engine having been set to work under the prescribed conditions, the test is begun at a certain predetermined time by commencing to weigh the oil, or measure the gas, as the case may be, and take other data concerned; after which the regular measurements and observations are carried forward until the end. When the stopping time arrives the test is closed by simply taking the final readings.

Records.—The general data should be taken and recorded in the same manner as that described hereafter.

Calorific tests and analyses.—The quality of the oil or gas should be determined by calorific tests and analyses made on representative samples.

Heat Consumption.—The number of heat units consumed by the engine is found by multiplying the heat units per pound of oil or per cubic foot of gas (higher value), as determined by calorimeter test, by the total weight of oil in pounds or volume of dry gas in cubic feet consumed.

Horse-power and Efficiency.—The indicated horse-power, brake horse-power, and efficiency are computed by the same methods as those explained on page 530.

Heat Balance.—The various quantities showing the distribution of heat in the heat balance given in Table 3 are computed in the following manner:

The heat converted into work per I.H.P.-hour. (2546.5 B.t.u.) is found by dividing the work representing 1 H.P., or 1,980,000 foot-pounds per hour by the number of foot-pounds representing 1 B.t.u., or 777.5.

The heat rejected in the cooling water is obtained by multiplying the weight of water supplied by the number of degrees rise of temperature, and dividing the product by the indicated horse-power.

The heat rejected in the dry exhaust gases per I.H.P.-hour is found by multiplying the weight of these gases per I.H.P.-hour by the sensible heat of the gas reckoned from the temperature of the air in the room and by its specific heat. The weight of the dry exhaust gases per I.H.P-hour is the product of the weight of fuel per I.H.P.-hour by the weight of the dry gases per pound of fuel. The latter is the product of the proportion of carbon in 1 pound of fuel by the weight of the dry gases per pound of carbon, which may be found by the formula

$$\frac{11\,CO_2+8\,O+7(CO+N)}{3(CO_2+CO)},$$

in which CO_2, O, CO, and N are percentages of the dry exhaust gases by volume.

When the weight of air supplied per pound of fuel is determined the weight of dry gas per pound of fuel may be found by the formula

$$1+\text{pound air per pound fuel}-9\,H,$$

in which H is the proportion of hydrogen in 1 pound of fuel.

The heat lost in the moisture formed by the burning of hydrogen in the fuel gas is found by multiplying the total heat of 1 pound of superheated steam at the temperature of the exhaust gases, reckoning from the temperature of the air in the room, by the proportion of the hydrogen in the fuel as determined from the analysis, and multiplying the result by 9.

The heat lost in superheating the moisture contained in the gas and air is determined by multiplying the difference between the temperature of the exhaust gases and that of the gas and air by the average specific heat of superheated steam for the range of temperature and pressure.

The heat lost through incomplete combustion is obtained by analyzing the exhaust

gases and computing the heat of the unburned products which would have been produced by their combustion.

The above rules do not apply to engines with hit-and-miss governors.

Data and results.—The data and results should be reported in accordance with the form given herewith (Table 3), adding lines for data not provided for, or omitting those not required, as may conform to the object in view. If a shorter form is desired, items given in fine print and designated by letters of the alphabet may be omitted. Unless otherwise indicated, the items should be the averages of the data.

TABLE 3

Data and Results of Gas or Oil Engine Test

(1) Test of........................engine, located at........................
To determine..
Test conducted by..

Dimensions, etc.

(2) Type of engine, whether oil or gas..
(3) Class of engine, (mill, marine, motor for vehicle, pumping, or other)...........
(a) Number of strokes of piston for one cycle, and class of cycle........................
(b) Method of ignition..
(c) Single or double acting..
(d) Arrangement of cylinders..
(e) Vertical or horizontal..
(4) Rated power..H.P.
(a) Name of builder..
(5) Number and diameter of working cylinders..............................in.
(a) Number and diameter of compression cylinders..............................in.
(b) Diameter of piston rods..in.
(6) Stroke of pistons..ft.
(a) Compression space referred to piston displacement..........................per cent
(b) Stroke of compression piston..ft.
(c) H.P. constant for 1 pound M.E.P. and 1 R.P.M..............................H.P

Date, Duration, etc.

(7) Date..
(8) Duration..hr.
(9) Kind of oil or gas..
(a) Physical properties of oil (specific gravity, burning point, flashing point).............

Average Pressure and Temperature

(10) Pressure of gas near meter..............................inches of mercury
(a) Barometric pressure..inches of mercury
(11) Temperature of gas near meter......................................degrees
(a) Temperature of cooling water, inlet......................................degrees
(b) Temperature of cooling water, outlet......................................degrees
(c) Temperature of air by dry-bulb thermometer................................degrees
(d) Temperature of air by wet-bulb thermometer................................degrees
(e) Temperature of exhaust gases at cylinder....................................degrees

Total Quantities

(12) Gas or oil consumed . . . . cu. ft., lb.
(13) Moisture in gas, in per cent by weight, referred to dry gas . . . . per cent
(14) Equivalent dry gas at 60° and 30 inches . . . . cu. ft.
(a) Air supplied . . . . cu. ft.
(15) Cooling water supplied to jackets . . . . lb.
(a) Water or steam fed to cylinder . . . . lb.
(16) Calorific value of oil per lb., or of dry gas per cu. ft. at 60° and 30 inches by calorimeter test (higher value) . . . . B.t.u.

Hourly Quantities

(17) Gas or oil consumed per hour . . . . cu.ft. lb.
(18) Equivalent dry gas per hour at 60° and 30 inches . . . . cu. ft.
(19) Cooling water supplied per hour . . . . lb.
(20) Heat units consumed per hour (Item 16×Item 18) . . . . B.t.u.

Analysis of Oil

(21) Carbon (C) . . . . per cent
(22) Hydrogen (H) . . . . per cent
(23) Oxygen (O) . . . . per cent
(24) Sulphur (S) . . . . per cent
(a) Moisture . . . . per cent
(b) Result of fractional distillations . . . .

Analysis of Fuel Gas by Volume

(25) Carbon dioxide (CO_2) . . . . per cent
(26) Carbon monoxide (CO) . . . . per cent
(27) Oxygen (O) . . . . per cent
(28) Hydrogen (H) . . . . per cent
(29) Marsh gas (CH_4) . . . . per cent
(30) Heavy hydrocarbon C_nH_m . . . . per cent
(a) Sulphur dioxide (SO_2) . . . . per cent
(b) Hydrogen sulphide (H_2S) . . . . per cent
(c) Nitrogen (N) by difference . . . . per cent

Analysis of Exhaust Gases by Volume

(31) Carbon dioxide (CO_2) . . . . per cent
(32) Carbon monoxide (CO) . . . . per cent
(33) Oxygen (O) . . . . per cent
(34) Nitrogen (N) . . . . per cent

Indicator Diagrams

(35) Pressure above atmosphere . . . . pounds per square inch
(a) Maximum pressure . . . . pounds per square inch
(b) Pressure at beginning of stroke . . . . pounds per square inch
(c) Pressure at end of expansion . . . . pounds per square inch
(d) Exhaust pressure at lowest point . . . . pounds per square inch
(36) Mean effective pressure . . . . pounds per square inch

Speed

(37) Revolutions per minute . . . . R.P.M.
(38) Average number of explosions or firing strokes per minute . . . .

(a) Variation of speed between no load and full load . . . . R.P.M.
(b) Momentary fluctuation of speed on suddenly changing from full load to half load. R.P.M.

Power

(39) Indicated horse-power . . . . I.H.P.
(40) Brake horse-power . . . . B.H.P.
(41) Friction horse-power by difference (Item 39 – Item 40)[1] . . . . Fr. H.P.

(a) Friction horse-power by friction diagrams . . . . Fr. H.P.

(42) Percentage of indicated horse-power lost in friction Item 41 . . . . per cent

Economy Results

(43) Heat units consumed by engine per I.H.P. per hour[2] . . . . B.t.u.
(44) Heat units consumed by engine per B.H.P-hour . . . . B.t.u.
(45) Dry gas at 60° and 30 inches consumed per I.H.P.-hour . . . . . pounds, cubic feet
(46) Pounds of oil or cubic feet of dry gas per B.H.P.-hour . . . . pounds, cubic feet

Efficiency

(47) Thermal efficiency referred to indicated horse-power . . . . per cent
(48) Thermal efficiency referred to brake horse-power . . . . per cent

Work Done per Heat Unit

(49) Net work per B.t.u. consumed (1,980,000 ÷ Item 40) . . . . foot-pounds

HEAT BALANCE

(50) Heat balance, based on B.t.u. per I.H.P. per hour . . . .

		B.t.u.	Per cent
(a)	Heat converted into work	2546.5	. . . .
(b)	Heat rejected in cooling water	. . . .	. . . .
(c)	Heat rejected in the dry exhaust gases	. . . .	. . . .
(d)	Heat lost due to moisture formed by burning of hydrogen	. . . .	. . . .
(e)	Heat lost in superheating moisture in gas and air	. . . .	. . . .
(f)	Heat lost by incomplete combustion	. . . .	. . . .
(g)	Heat unaccounted for, including radiation	. . . .	. . . .
(h)	Total heat consumed per I.H.P.-hour, same as Item 38	. . . .	. . . .

Sample Diagrams

(51) Sample indicator diagrams from each cylinder and if possible a stop-motion light-spring diagram showing inlet and exhaust pressures . . . .

OPERATION AND CORRECTION

General remarks.—With the hot-surface type of oil engine, the attendant, to obtain the best results in operation, should first carefully read the instructions accompanying his engine; he should then fully understand the principles of his engine and how to procure proper combustion in the cylinder. The explosive mixture in all designs of

[1] In two-cycle engines this includes the power required for compression.
[2] If these results, in the case of a gas engine, are based on the low value of the heat of combustion that fact should be so stated.

these engines consists of (*a*) hydrocarbon vapor introduced into the vaporizer or combustion space as described on page 544 in different ways in the various engines and (*b*) atmospheric air also introduced into the cylinder by the outward movement of the piston in the four-cycle type, or impelled into the cylinder from the scavenging air pump, or from the crankcase in the crankcase compression type of two-cycle engine at about 2 to 6 pounds pressure. This mixture of vapor and air is then suitably compressed by the inward movement of the piston and is ignited by contact with the hot surface, hot tube, electric coil or otherwise, and the impulse or power stroke of the piston follows. The exhaust period afterwards takes place. If these conditions do not properly exist correct operation will not follow, and the cause for improper working may be found by examining the following points.

Ignition in all types is dependent on: (*a*) proper pressure of compression in the high-pressure type or (*b*) on this condition together with proper temperature of the hot surface or other device in the low-pressure engines. Insufficient pressure is probably due to leakage of some moving part or valve. Insufficient temperature of igniting part may be traced to too great a cooling water circulation, to carbonized or unclean surfaces, or to possible water leakage into combustion space.

Oil supply to the cylinder should be correctly timed (see diagrams Fig. 43, and also the instructions for operation of the particular make of engine). The correct quantity of fuel must be furnished; too much oil makes the mixture too rich and will prevent proper combustion, and too little oil will make the mixture too poor. An air pocket in the oil-supply piping, pump or valves, etc., will frequently prevent proper oil supply to the combustion space. The color of the exhaust gases will frequently indicate whether the oil supply is correct. Too much oil will usually entail black or quite a visible exhaust. The exhaust gases should be invisible or nearly so. Too small a supply of fuel will be shown by inadequate power being developed.

The air supply in the four-cycle type is dependent on proper opening and closing of the air-inlet valve (see diagram Fig. 43) and on absence of leakage by the valves or piston; in the two-cycle type it is dependent on absence of leakage in the crankcase or air pump, and in either type obstruction of air passages may prevent proper air supply. A low-pressure indicator card will show the cause if the air supply is incorrect.

Oil spray to the vaporizer, etc., should be sharp, without drip, and should be such that the vapor or globules of petroleum are thoroughly distributed throughout the whole space of the vaporizer or combustion space. The vapor should be intimately mingled with air and the globules should have their maximum surface exposed to the oxygen. The speed of the spray as it enters the combustion space and the correct period during which it enters this space are important and are controlled by the shape of the cam actuating the fuel pump and by the size of the spray nozzle. Diagrams Fig. 43 show the proper period of fuel injection in representative types of engines.

Knocking in the hot surface oil engine may be caused by (*a*) loose bearings in the connecting rod or in the main crankshaft bearings, (*b*) loose flywheel keys, (*c*) improper timing of ignition which may be due to too high compression pressure or to too early injection of the fuel or to operating with insufficient cooling-water circulation. Indicator cards taken with full load should show the cause in any event. The ignition line hould appear perpendicular to the atmospheric line as seen in Fig. 42. With air blast injection the remarks made with reference to Diesel engines can also be studied.

Deficient power may be due to a variety of causes: (*a*) increased friction in the moving parts caused by improper lubrication; (*b*) sticky or gummy deposit on the piston, which, when operating properly, should be clean, with proper film of clean lubricant surrounding it; (carbonized or clogged piston rings will allow carbon to be blown past them and may then require removal or cleaning); (*c*) improper cooling effect which allows the piston to expand unduly, causing greater friction, and possibly to become

distorted; (*d*) overheating of other moving parts, bearings, etc., causing greater friction and loss of power; (*e*) inadequate fuel supply due to leaky fuel inlet valves or leaking pump valves or plungers; (*f*) a clogged oil filter or a pocket of air in the fuel supply connections causing improper supply of fuel;. (*g*) improperly timed ignition of the explosive mixture; (*h*) a leakage of the air inlet or exhaust valves or piston rings causing loss of compression pressure. Careful examination of the parts above referred to should enable the attendant to ascertain the reason for deficient power, but indicator cards must be taken if the cause cannot otherwise be traced.

Piston blowing may be due to various causes, (*a*) improper lubrication or use of lubricant unsuitable for this special purpose, as specified elsewhere; (*b*) piston rings which have become carbonized and stick in their grooves, or have become worn so that they do not make a tight fit in the cylinder liner; (*c*) piston and rings scored or cut by grit or dirt which has come in contact with them. (*d*) overheating and uneven expansion caused by insufficient water cooling. If the blowing of the piston cannot otherwise be remedied new piston rings must be put in place and in some cases it is even necessary to rebore the cylinder and supply a new piston and rings. Occasionally lubricant splashing against the heated back end of piston and vaporizing will cause vapor to issue from the open piston end. This may be taken erroneously to be leakage past the rings.

Leakage of air inlet and exhaust valves will of course result in defective operation. In the smaller sizes an engine can be turned backwards by hand on the compression stroke and if these valves and the piston are tight it will be impossible or difficult to turn the piston past the inner dead center. In larger engines tightness of the exhaust valve can be tested by turning the crank until the piston is on the inner dead center at the beginning of the combustion stroke. The valve can then be opened and the air from the starting tank allowed to fill the combustion space and valve chambers. The engine cannot start, being exactly on dead center, and any leakage past the exhaust valve will be heard through the test cock opened on the exhaust piping. A leaky valve should be taken out and ground in with carborundum powder until the seat is perfect all around it. If necessary and if the exhaust valve is badly pitted it must be trued up in a lathe.

Utilization of waste heat.—In some installations the waste heat from the exhaust and water jackets can be advantageously used for manufacturing purposes, etc. As heat is only available when the engine is in operation an auxiliary heater must be installed in addition, and therefore for general heating purposes the waste heat from oil or Diesel engines cannot be advantageously utilized. The heat balance of a representative hot surface oil engine is as follows:

TABLE 4

	B.t.u.		B.t.u.
Fuel consumed, taking .6 pound with 18,500 B.t.u. per pound, $18,500 \times 6 =$	11,100	Heat equivalent of B.H.P. (82 per cent mechanical efficiency)	3,330
		Heat lost to circulating water...	4,440
		Heat lost in exhaust gases......	2,775
		Heat lost in radiation and other losses......................	555
	11,100		11,100

To utilize this heat the exhaust gases are passed through a boiler or similar apparatus which is arranged so as to be easily cleaned, because deposits of carbon and other substances are left by the exhaust gases. Water may be heated in this chamber, which must be properly insulated and placed as close as possible to the engine. Assuming

the efficiency of the latter to be 68 per cent approximately 1887 B.t.u. per B.H.P. per hour can be obtained from the exhaust gases alone. From the circulating water which issues at temperatures varying from 120° F. to 180° F. in different makes of engines the whole of this heat can be utilized with suitable arrangements for doing so.

A complete installation of a horizontal hot surface type stationary oil engine is shown in Fig. 44. The different methods of furnishing the cooling water with the open or

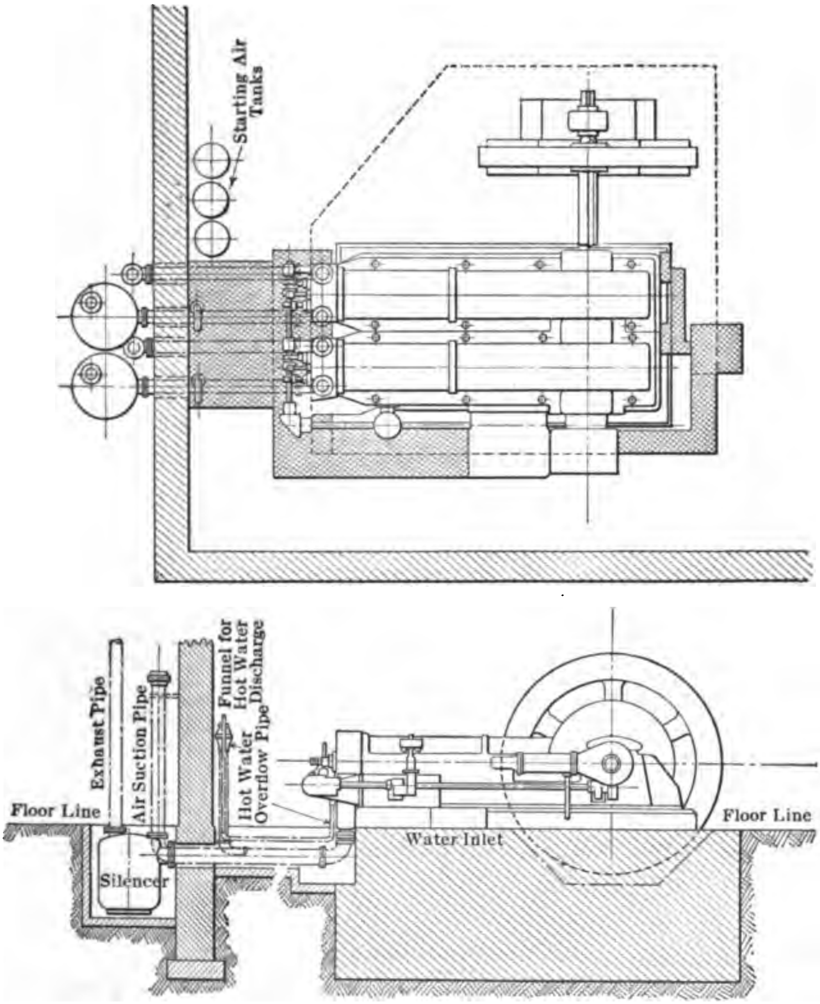


Fig. 44.—Complete installation hot surface type.

enclosed system are described on page 576. The sizes of air inlet and exhaust pipe are also there referred to. The amount of cooling water required with many hot surface engines is greater, and at least 10 gallons per B.H.P. hour should be provided, instead of the 5 gallons required with the Diesel engine. Formulæ given or sizes recommended for the air inlet and exhaust pipes as outlined in connection with the Diesel engine installation are equally applicable to this type.

Table 5 shows heat balance of various engines compiled by Dr. C. E. Lucke and reproduced by his permission from. "Thermodynamics."

TABLE 5

Heat Balances of Gas and Oil Engines.—LUCKE

(Per cent of gas or oil heat)

Engine and authority	I.H.P.	B.H.P.	Friction	Exhaust	Jacket	Radiation and unaccounted for
Donkin	22.32	.....	.....	43.29	32.96	1.43
Beck engine (Kennedy)	19.4	.....	.....	42.9	33.0	4.7
Griffin engine (Kennedy)	21.1	.....	.....	39.8	35.2	3.9
Atkinson engine (Kennedy)	25.5	.....	.....	37.9	27.0	9.6
Otto Crossley engine (Kennedy)	22.1	.....	.....	35.5	43.2	.8 excess
Comp. Ratio R.P.M. (Slaby)						
2.67 187 7.11 (Slaby)	18.0	.....	.....	30.8	51.2	....
2.67 247 7.35 (Slaby)	18.1	.....	.....	36.3	45.6	....
4.32 187 7.43 (Slaby)	24.4	.....	.....	21.8	53.8	....
4.32 247 7.40 (Slaby)	23.7	.....	.....	26.8	49.5	....
General (Mathot)	33.0	28.0	5.0	31.0	36.	....
Westinghouse 300 H.P. (Bibbins)	29.48	24.9	4.58	36.3	34.22	....
300 H.P. engine 197 H.P. (Eberly)	43.5	33.5	10.0	24.1	34.3	1.9 excess
300 H.P. engine 294 H.P.	45.8	32.2	13.6	23.9	31.8	1.5 excess
300 H P. engine 335 H.P.	41.5	30.9	10.6	24.8	33.8	.1 excess
6 H.P. engine I. C. E.	31.8	26.7	5.1	41.1	27.1	....
24 H.P. engine I. C. E.	33.3	28.3	5.0	37.1	29.6	....
Deutz 2 H.P. (Wimplinger)	21.5	16.1	5.4	25.0	50.4	3.1
Güldner 20 H.P. Schroeter	42.7	.....	.....	24.1	33.2	....
Walruth 75 H.P.	27.1	21.3	5.8	23.4	49.5	....
300 H.P. Goldsmith and Harding	24.4	17.1	7.3	50.6	25.0	....
Hornsby (Robinson)	21.0	18.0	3.0	29.0	50.0	....
De La Vergne "FH" (Towl)	40.14	27.52	12.62	20.03	26.50	13.33
Pierce-Arrow (Chase)	.....	18.0	.....	.....	29.0	....

DIESEL ENGINE

Introductory.—The previous remarks have applied to the hot-surface type of oil engine, sometimes referred to as the semi-Diesel type. The following data refer to the Diesel engine exclusively. Dr. Rudolf Diesel originally patented his engine in August, 1892, and the first successful engine was constructed under these patents by the Maschinen-Fabrik, Augsburg, in 1897. The first Diesel engine operated in the United States was that installed at Madison Square Garden, New York City, in 1898. Dr. Diesel in a treatise [1] described the features of his engine as it was originally planned to

[1] Theory and Construction of a Rational Heat Motor, 1894, published by E. and F. N. Spon, London.

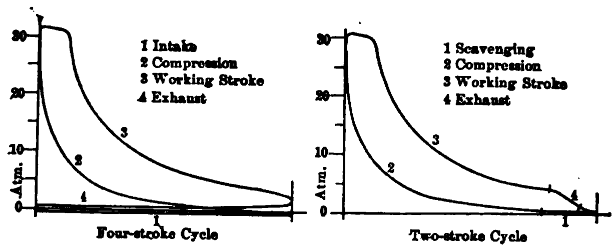


Fig. 45.—Diesel indicator card.

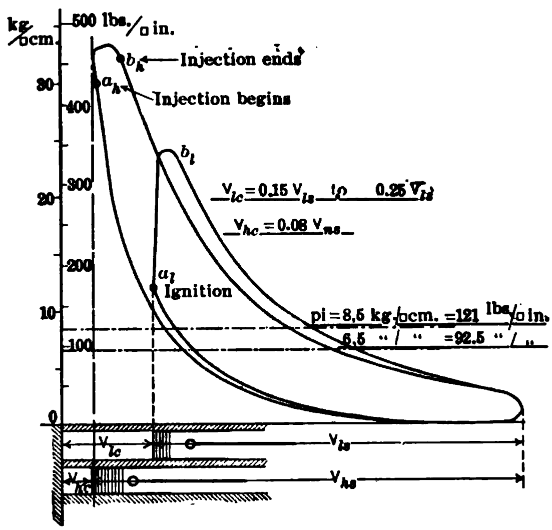


Fig. 46.—Superimposed diagrams.

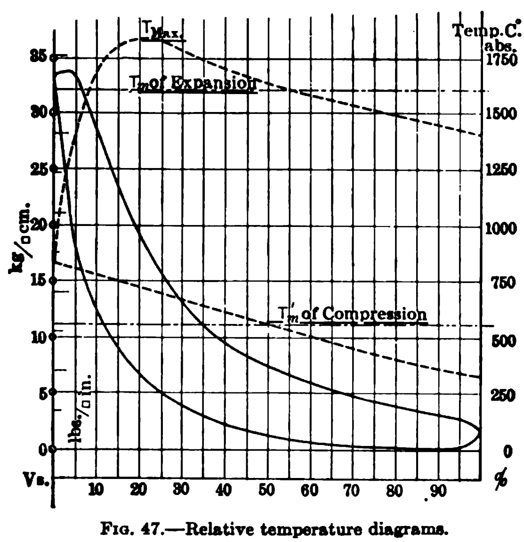


Fig. 47.—Relative temperature diagrams.

operate on the Carnot cycle, but thermodynamic and structural difficulties necessitated the modification of these original plans before the first successful Diesel engine was constructed. This engine proved even then and still continues to be the nearest approach to the Carnot cycle, and possesses the highest thermal efficiency of any engine yet constructed. The characteristic feature of its working cycle, briefly stated, is the com-

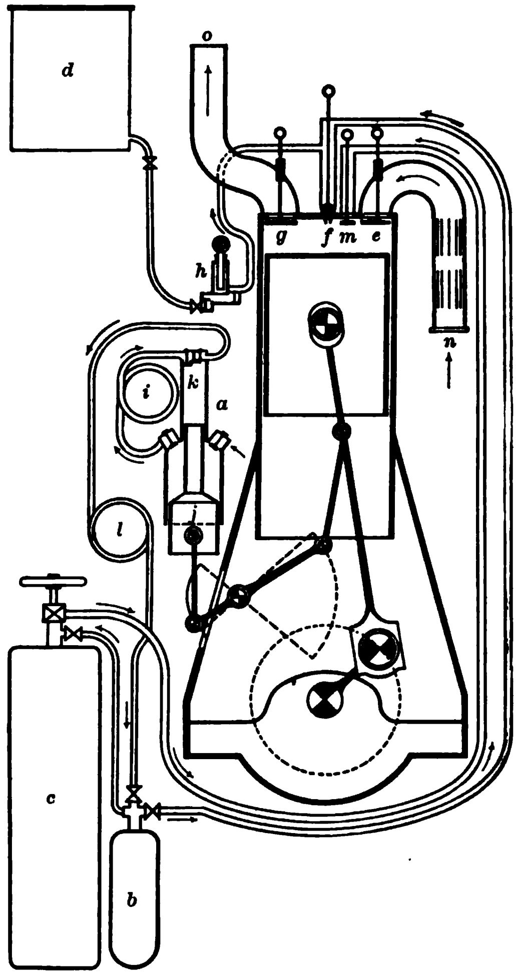


FIG. 48.—Four-cycle Diesel engine. (a) Air compressor. (b) Injection air tank. (c) Air receiver. (d) Fuel tank. (e) Air inlet valve. (f) Fuel inlet valve. (g) Exhaust valve. (h) Fuel supply pump. (i) Intercooler. (j) Air compressor. (k) High-pressure cylinders. (l) After cooler. (m) Starting valve. (n) Air inlet pipe. (o) Exhaust pipe.

pression of air only in the cylinder. That pressure is raised to a degree where sufficient temperature is developed to cause ignition of the vaporized or atomized fuel injected after the process of compression is completed. The period of fuel injection is continued while the piston commences to move outward thus the pressure as shown on the indicator card remains constant during that part of the outward stroke of the piston, as shown

in Fig. 45. Accordingly the Diesel engine is classified as a " constant pressure " engine. The diagram in Fig. 46 shows two indicator cards superimposed and serves to illustrate the comparative pressures and other features of the constant-volume and constant-pressure type of engine. In the lower part of the diagram the relative clearances and mean

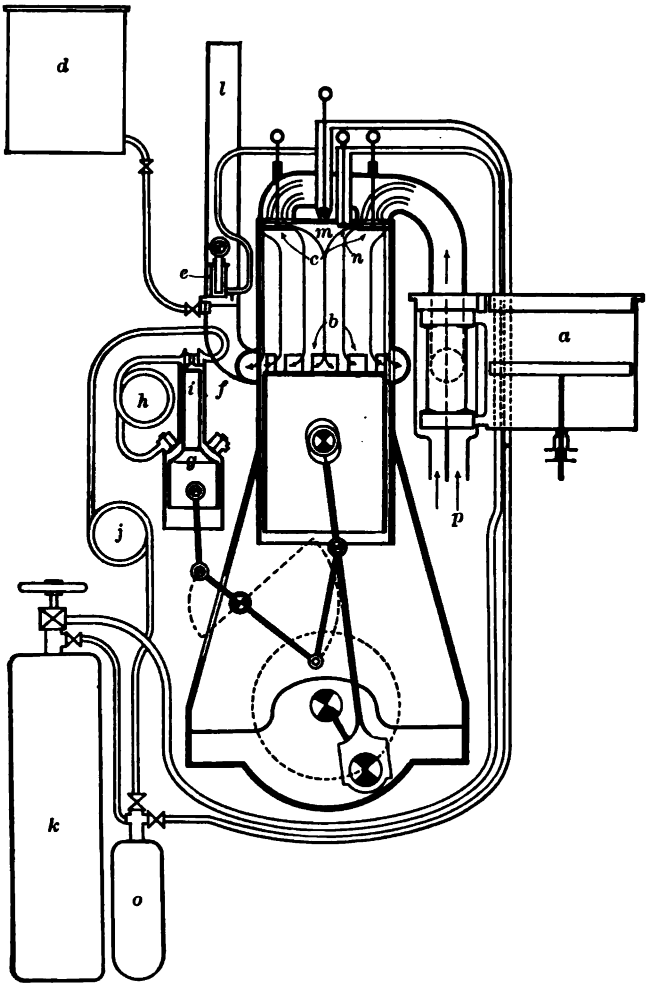


FIG. 49.—Two-cycle Diesel engine. (*a*) Scavenging air pump. (*b*) Exhaust ports. (*c*) Air valves. (*d*) Fuel tank. (*e*) Fuel-supply pump. (*f*) Air compressor. (*g*) Low-pressure cylinder. (*h*) Intercooler. (*i*) High-pressure cylinder. (*j*) After cooler. (*k*) Air receiver. (*l*) Exhaust pipe. (*m*) Fuel-inlet valve. (*n*) Air-starting valve. (*o*) Injection air tank. (*p*) Air-inlet pipe.

effective pressures are approximately indicated. The smaller diagram may be taken as fairly representative of a constant-volume type where the vapor and air are subjected to combustion suddenly. The larger diagram represents a Diesel engine where the ignition or combustion line is nearly horizontal and indicates constant pressure. Fig. 47 shows approximate relative temperatures and pressures of a Diesel type during

compression and expansion strokes. Those indicated are absolute temperatures as computed by Mallard and Le Chatelier, based on the change of specific heat. Diagrammatic illustrations, Fig. 48 and Fig. 49, show the elements of a two-cycle and a four-cycle Diesel engine with description of the various parts of each type.

The periods of each process of the cycle of both two- and four-cycle Diesel engines are shown on the indicator diagrams reproduced on Fig. 50 and Fig. 51, and the positions of the crank pin during each process are shown on Fig. 51. for the two-cycle and on Fig. 50 for the four-cycle type.

The thermal efficiency of a four-cycle modern Diesel engine operating at or near full-load capacity may be taken as 32 to 35 per cent with the actual or Brake H.P. and 41

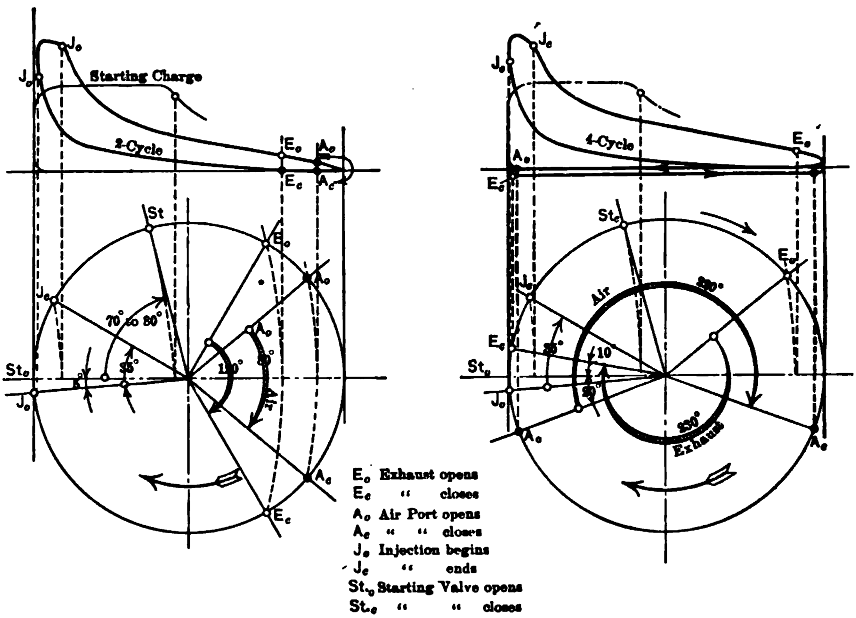


Fig. 51.—Two-cycle indicator car processes. Fig. 50.—Four-cycle indicator car processes.

to 45 per cent with the indicated H.P. The two-cycle type, under similar conditions, is approximately 3 per cent less than the four-cycle engine. The heat balance of an average Diesel engine may be taken as follows:

Table 6[1]

	Per cent	B.t.u.
Heat equivalent of work done + friction and pumps	43	7,955
Carried away by cooling water	33	6,105
Rejected in exhaust gases	23	4,255
Radiation and other losses	1	185
Total	100	18,500

The general design of the chief parts of Diesel engines of the horizontal and vertical types is shown in the various illustrations given herein, both of the four-cycle and two-

[1] Reproduced from Diesel Stationary and Marine Engines, by A. H. Goldingham.

cycle types. Diesel engines are built (*a*) horizontal, slow-speed in single and multi-cylinders from about 75 B.H.P. to about 1500 B.H.P. for stationary purposes, (*b*) vertical slow-speed from about 75 B.H.P. to about 3000 B.H.P. in six cylinders, both for stationary and marine installations, (*c*) vertical high-speed multi-cylinders (up to 12 cylinder) for submarine work and also for direct connection to electric generators, (*d*) double-acting, both vertical and horizontal, in larger sizes up to about 12,000 H.P. These latter designs at this (1921) writing are more or less in the development stage.

Advantages of the horizontal design are greater accessibility of valves and valve motion and piston; the vertical type has the advantage of occupying about two-thirds of the space of the horizontal type; it requires also somewhat less concrete foundation as the free force is in the vertical plane. With multi-cylinder vertical engines the cost of production is usually less than with the single-cylinder horizontal design.

A comparison of two- and four-cycle type Diesel engines at the present time seems to show the latter type to be more favored both for stationary and marine installations. A recent canvass of Diesel engines under construction in Great Britain showed that 84 per cent were of the four-cycle, and 16 per cent were of the two-cycle design.

In the controversy which now exists among engineers the advocates of each type refer to the advantages of the two or the four-cycle design. Those favoring the four-cycle Diesel engine point out:

1. The greater simplicity of the single-acting engine, especially for marine installations.

2. The lower range of temperatures of the four-cycle design, owing to the longer period between the impulses in the combustion space and the greater percentage of the complete cycle in which a cooling effect from cooling water and incoming air obtains.

3. More complete scavenging of the products of combustion from the cylinder and combustion space.

4. Better lubrication of the piston, which can be maintained at a lower temperature than with the two-cycle, and more effective lubrication of main crankshaft bearings due to the reduced pressure on the film of oil during the air inlet stroke.

The advantages of the two-cycle type over the four-cycle are referred to as follows:

1. Elimination of exhaust valves and air-inlet valves and valve motion and simplified reversing mechanism in marine installations.

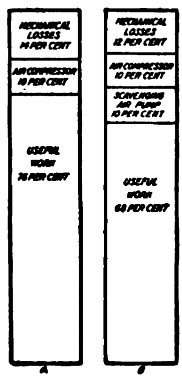


FIG. 52.—Losses two- and four-cycle Diesel engine (Haas).

2. Less space occupied, and total weight of two-cycle about 70 per cent of that of the four-cycle type.

3. More even turning movement of crankshaft and less vibration at the stern of ship in marine installations.

4. Reduced flywheel size. To eliminate the dead center only four cylinders are necessary whereas the four-cycle type requires six cylinders for this effect.

(The advantages of the two-cycle Diesel marine engine as made in Italy were fully described by M. G. Chiera in "Engineering," London, Nov. 1st, 1918).

The mechanical efficiency of both two and four-cycle Diesel engines varies in different designs and is stated definitely in the different test sheets appended. The injection air-blast compressor absorbs approximately 10 per cent of the total power developed at full load with both two- and four-cycle types. With the two-cycle type the power absorbed by the scavenging air pump in addition is approximately 10 per cent. With solid injection engines, where no injection air blast is used, the compressor is not required and the over-all mechanical efficiency is practically 10 per cent greater. Fig. 52 shows

these losses at full load with the air blast types [1] for both two- and four-cycle types.

The design and construction of representative Diesel engines and the various methods of the general arrangement of the bed plates containing the crankshaft main bearings in vertical design and the engine frames of the horizontal engine in most types containing the cylinder liners are also shown in the various sectional views.

The cylinder liner in both stationary and marine engines is generally cast separately, although in smaller marine engines some makers cast the liner and cylinder casing in one piece. The tension load is taken through the cylinder casing and the radial stresses are taken by the liner. In some designs the tension stresses are taken solely by long bolts passing from the bed plate to the cylinder head, as shown in Fig. 105. The liner is made of hard close-grained cast iron, having a tensile strength of about 35,000 pounds per square inch. It is usually inserted into the cylinder casing held rigidly at its back or upper end, supported in the center and held in place by a rubber ring at its front or lower end; thus the expansion (due to varying temperatures of the inner liner and outer casing when in operation with the cooling water jacket between them) is allowed for. The combustion pressure varies from 460 to 600 pounds per square inch. In high-speed engines and also when heavy tar oils are used 700 pounds per square inch is developed; assuming an average pressure of 510 pounds[2] per square inch of piston area, the pressure on piston (P) would be:

$$P=510\times0.785D^2=400D^2,$$

where D = diameter of cylinder.

The thickness (S) of cylinder liner may be taken as:

$$S=0.07D \text{ inch.}$$

To this add ½ inch to thickness of metal as allowance for reboring the liner when it becomes worn. With more than 15 inches diameter the liner thickness of metal may be gradually decreased toward the open end to 75 per cent of S.

The cylinder casing or jacket wall has to withstand in the direction of its axis a pulling force $P=400d^2$. The cross-sectional area $A=\pi Ds$. The stress per square inch

$$P=\frac{400\times d^2}{\pi Ds}, \quad \text{or} \quad S=\frac{400\times d^2}{\pi Dp\frac{1}{2}},$$

and let $p=1800$ pounds per square inch.

We get
$$S=0.071\frac{d^2}{D}.$$

Valves.—The inlet valve is designed for a mean velocity of 120 to 140 feet per second.

$$a=\frac{V}{v} \text{ square feet,}$$

or

$$a=\frac{F\times c}{v} \text{ square feet,}$$

[1] Reproduced from the Diesel Engine, by H. Haas, published by U. S. Bureau of Mines.

[2] Guldner takes combustion pressure as equal to 500 pounds.

where V = displacement of cylinder in cubic feet per second;
v = mean velocity in feet per second;
a = area of valve in square feet;
c = piston speed in feet per second;
F = area of piston in square feet.

The exhaust valve is usually made of the same size as the air-inlet valve.

Exhaust ports with two-cycle engines generally occupy half the circumference of the cylinder and are of such height as to allow proper opening and closing by the piston.

Cylinder-head bolts should be of good wrought iron or soft steel with an allowable tensile stress of 5500 to 6500 pounds per square inch. Size of bolts is determined by maximum pressure $(P_t) = 400\ D^2$, 20 to 30 per cent added for tightening.

Cylinder cover.—Owing to considerable trouble in older types of Diesel engines great attention has been devoted to the design of this part in modern engines. The cover is usually composed of tough, close-grained, soft charcoal iron. In the four-cycle type the air-inlet and exhaust valves, fuel-inlet valve and starting valve housings are inserted into the cylinder cover, and great care has been exercised to allow proper water circulation around these parts and also to arrange that the casting be as simple

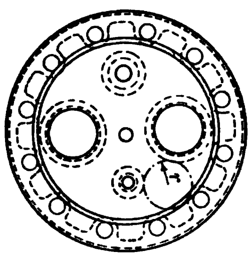


Fig. 53.—Cylinder cover.

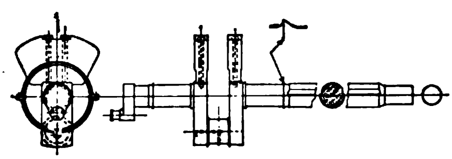


Fig. 54.—Crankshaft stationary Diesel engines.

as possible. Thickness of metal (S) of the cover is difficult to compute because of the complexity of its form and unknown casting strains. A simple design has,

$$S = \sqrt{\frac{r^2}{6}},$$

where S = thickness of metal of the inner wall of cover;
r = radius of the largest circle it is possible to describe on the plain surface of metal existing between the different supports for valves, etc., as shown in the sketch Fig. 53.

Crankshaft.—The design and construction of Diesel engine crankshafts is treated very fully in different treatises [1] and as it requires considerable space will be only briefly referred to here. Fig. 54 shows a representative crankshaft for stationary engines. It is forged in one piece and composed of material having ultimate tensile strength of 80,000 pounds per square inch minimum, its elastic limit being not less than 48,000 pounds per square inch with a limit of elongation in 2 inches of 25 per cent and reduction in area being not less than 45 per cent.

[1] Guldner, Bach, Haeder.

The following formula is derived from good average stationary Diesel engine practice. (See Fig. 55.)

$$a=2.2D. \qquad d'=0.55D. \qquad d=0.60D,$$

$$l=\frac{D}{1.65}. \qquad L=0.85D. \qquad h=0.6d. \qquad b=1\tfrac{1}{4} \text{ to } 1\tfrac{1}{2}d.$$

The dimensions h and b assume that the crankshaft has also an outboard bearing. Some makers are now employing built-up crankshafts for stationary practice. A representative built-up shaft for a horizontal Diesel engine is shown at Fig. 56.

Crankshafts, either forged in one piece or "built up," on both hot surface (low compression) and Diesel engines of various designs have the following dimensions:

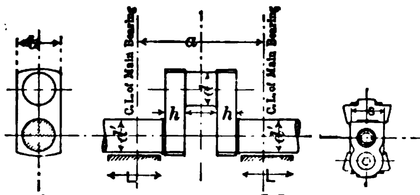


FIG. 55.—Diesel engine crankshaft.

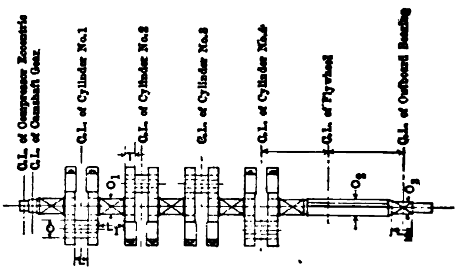


FIG. 56.—Built-up crankshaft.

Type engine	Low compression	Low compression	Low compression	Diesel	Diesel	Diesel	Diesel
H.P. (one cyl.)	25	40	65	50	100	140	180
Type shaft	Forged	Forged	Either	Forged	Either	Either	Either
Diameter crank pin	4″	5½″	6½″	7½″	8″	10″	13″
Length crank pin	4½″	5½″	7½″	7″	8½″	11″	10″
Diameter main bearing	4″	4¾″	6″	6¾″	8¼″	10″	11″
Length main bearing	9″	11½″	13¼″	9½″	14½″	17½″	18¼″
Dia. flywheel section	4″	5¾″	7″	7½″	9½″	11⅜″	11⅝″
Dia. outboard bearing	.....	3½″	5″	6″	7″	8″	9″
Length outboard bearing	.....	7″	8″	8″	10″	11″	15″
Thickness crank web forged	2¾″	3¾″	4¾″	3½″	5½″	6¾″	6⅞″
Do. built up	.....	.....	5″	....	5⅝″	7″	7⅝″
Width crank web forged	5″	7¼″	8″	15″ dia. circular	12½″	13″	15″
Do. built up	.....	.....	12″	....	18″	10″	26″
Dia. coupling end	4″	3½″	6″	....	7″	8″	9″

Marine Diesel crankshafts.—Lloyd's rules require the following dimensions: Where the maximum pressure in the cylinder does not exceed 500 pounds per square inch, the diameters of the crankshaft are not to be less than those given by the following formula:

$$\text{Diameter of crankshaft}=\sqrt[3]{D^2\times(AS+BL)},$$

where D = diameter of cylinder;

S = length of stroke;

L = span of bearings adjacent to a crank measured from inner edge to inner edge.

The values of $(AS+BL)$ are as follows:

4-cycle S. A. engine	2-cycle S. A. engine	Values of coefficient
4 or 6 cylinders	2 or 3 cylinders	$.089S+.056L$
8 cylinders	4 cylinders	$.099S+.054L$
10 or 12 cylinders	5 or 6 cylinders	$.111S+.052L$
16 cylinders	8 cylinders	$.131S+.050L$

For the auxiliary Diesel engines, diameters may be 5 per cent less than above. In solid forged shafts the breadth of the webs should not be less than 1.33 times and the thickness not less than 0.56 times the diameter of the shaft as found above, or, if these proportions are departed from, then the webs must be of equivalent strength. Where no flywheel is employed, diameter of intermediate shaft must not be less than that given by this formula.

$$\text{Diameter of intermediate shaft} = \text{coefficient } \sqrt[3]{D^2 \times S},$$

where D = diameter of cylinder;
S = stroke of piston.

The value of the coefficient is given below:

4-cycle S. A. engine	2-cycle S. A. engine	Value of coefficient
4 cylinders	2 cylinders	.456
6, 8, 10 or 12 cylinders	3, 4, 5, or 6 cylinders	.436
16 cylinders	8 cylinders	.466

Where the stroke is between 1.2 times to 1.6 times the diameter of the cylinder $(.735D+.273S)$ may be substituted for $\sqrt[3]{D^2 \times S}$. If the maximum pressure in the cylinders exceeds 500 pounds per square inch the diameters of shafting throughout must be increased in the proportion:

$$\sqrt[3]{\frac{\text{Maximum pressure in pounds per square inch}}{500}}.$$

In a paper read in July, 1916, before the Diesel Engine Users' Association (London) Mr. H. P. Smith recommended the following dimensions of Diesel crankshafts with material composed of steel with 75,000 pounds tensile strength and with proper care in design to preserve correct bearing alignment, the unit being the cylinder bore.

Diameter of crank pin and journal:	0.525 to 0.54
Length of journal:	0.75 to 0.80
Length of crank pin:	0.524 to 0.54
Thickness of web:	0.32 minimum.

Balancing of the reciprocating and rotating parts recommended by Haeder & Huskisson is as follows, taking account of the inertia:

For horizontal engines:

$$W_1 = 0.7(W_2+W_3)\frac{r}{R} \text{ pounds},$$

and for vertical engines:

$$W_1 = W_2\frac{r}{R} \text{ pounds},$$

where W_1 = Weight of the balance weight in pounds;
R = Radius of the center of gravity of the balance weight in feet;
W_2 = Weight of the crank pin and the big end of the connecting rod + half the weight of the body of the connecting rod in pounds;
r = Throw or radius of the crank in feet;
W_3 = Weight of the piston and piston pin in pounds + half the body of the rod and small end.

Trunk pistons are used with numerous stationary Diesel engines as well as with marine type of 21 inch diameter, both uncooled and with water or oil cooling arranged to circulate internally; but for marine work the crosshead type as shown in Fig. 105 is always preferred, except in cases such as high-speed submarine types where total height of engine necessitates lowest limits of this dimension. For horizontal engines uncooled the design of the trunk piston shown in Fig. 57 is considered good representative practice. Here the thickness of metal (hard, close-grained cast iron) of the concave head

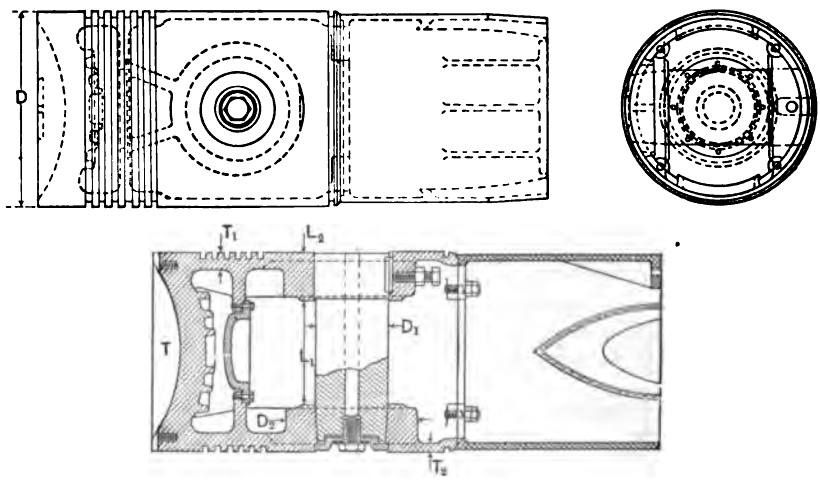


FIG. 57.—Trunk piston uncooled.

is approximately 5 inches. The piston is constructed in two parts with ground joint and bolted together. The dimensions of the various parts of the piston shown in Fig. 57 are for Diesel engines or hot surface type:

D_1, diameter of wrist pin	0.3–$0.4D$
L_1, length wrist-pin bearing	$0.5D$
L_2, length wrist-pin bearing	in piston $0.25D$
D_2, diameter of wrist-pin boss	$0.2D$
T, thick head of piston	0.08–$0.125D$

Thickness of metal must be sufficient to insure proper cross-section of metal to allow for radiation whether ribs reinforce it or not.

T_1, thickness of barrel-head end	0.09–$0.1D$
T_2, thickness of barrel-crank end	0.06–$0.075D$
No. of piston rings	6–7
Width of piston rings	$\frac{3}{8}''$–$\frac{1}{2}''$
Depth of piston rings, grooves	$\frac{5}{8}''$–$\frac{3}{4}''$

Vertical engines carry a wiper ring as shown at rear end of piston; also an oil catcher. Clearance-head end taper to rear of last piston ring for expansion-head end 2½/1000 per inch diameter tapering off to 1½/1000 per inch diameter on body.

Piston with crosshead shown in Fig. 105 is made of such length as to accommodate the piston rings only. The method of circulating the cooling medium in the four-cycle engine is shown in Fig. 91. In the two-cycle type the existence of air-inlet and exhaust ports (see Fig. 88) necessitates the lengthening of the piston so as to prevent the uncovering of such ports when the piston is at the top center.

Water or oil cooling of piston is necessary when its diameter is over 21 inches or thereabouts. Some builders prefer cooling smaller pistons than 21-inch diameter, but the process of conducting the water to and from the moving piston has been troublesome and has received great attention from designers to avoid the constant wear of the telescopic or sliding surfaces which necessitates frequent adjustment to prevent leakage of the water. The types of apparatus of this description seen in Fig. 91 and Fig. 117 have had greater success than others.

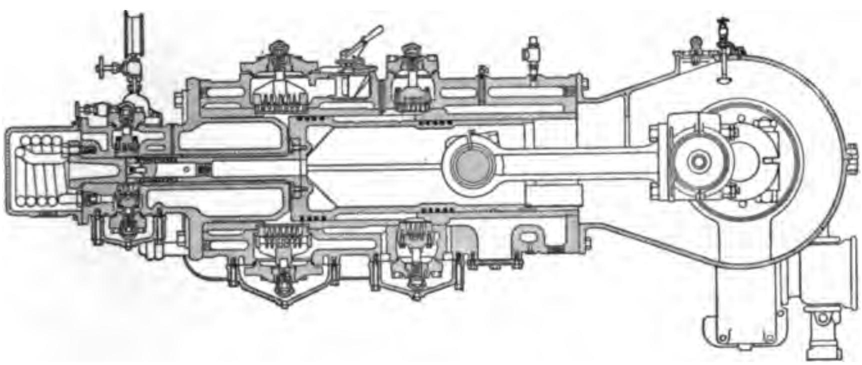


FIG. 58.—Three-stage air compressor (Snow).

Crosshead.—Oil engines of all types developing over 180 B.H.P. in one cylinder are better arranged with crosshead and guides than with trunk piston. The advantages of the crosshead are:

1. The guides are maintained at an even temperature and are not affected by the contraction and expansion of the cylinder as is found with the trunk piston.

2. Lubrication of the crosshead is simpler as it does not come in contact with the heated parts of the engine as does the trunk piston.

3. As the guides become worn they can easily be adjusted.

4. Possibility of piston seizing through overheating or from improper lubrication is minimized where a crosshead is employed. These remarks apply to the single-acting type. The crosshead is always employed with the double-acting type.

Air compressors.—A very important part of all Diesel engines (except in those types having solid injection) is the air compressor furnishing the injection air at 700 to 1200 pounds pressure per square inch to the sprayer or pulverizer. This air is injected into the combustion space with the fuel. An excellent and representative type of three-stage compressor is shown in Fig. 58, as built by the Worthington Pump and Machinery Corporation and attached to their horizontal Snow Diesel Engine. It is equipped with Laidlaw feather valves which consist of strips of light steel restrained at the ends and free to lift from the flat seat in the center, thus permitting the passage of air to the valve seat by contact and not by impact. The intercoolers for the low and intermediate stages are provided by the water jacket and that for the high-pressure stage is provided by the coil of

pipe placed in the water chamber. The method of actuating the compressor direct from the main crankshaft is illustrated in Fig. 87. In some larger stationary installations the air compressor forms a separate unit operated by an auxiliary engine. Frequently two units of this description are installed so as to insure continuous service. In Fig. 59, illustrating the De La Vergne Diesel Engine, the air compressor is a separate unit and is actuated from the main crankshaft through a flexible coupling. This arrangement is very accessible and has proved to be satisfactory. The displacement of the low-pressure stage of the compressor with four-cycle single-acting engines should exceed 0.3 cubic foot per minute per B.H.P. or 18 cubic feet per B.H.P. per hour. Small high-speed type Diesel engines require a somewhat greater amount of air and two-cycle type about 10 per cent more air. With a three-stage compressor the volume of the different stages varies from 1 : 4 : 4 to 1 : 5 : 5. The area of the air-inlet valve can be approximately one-tenth of the area of the piston and the area of the discharge valve approx-

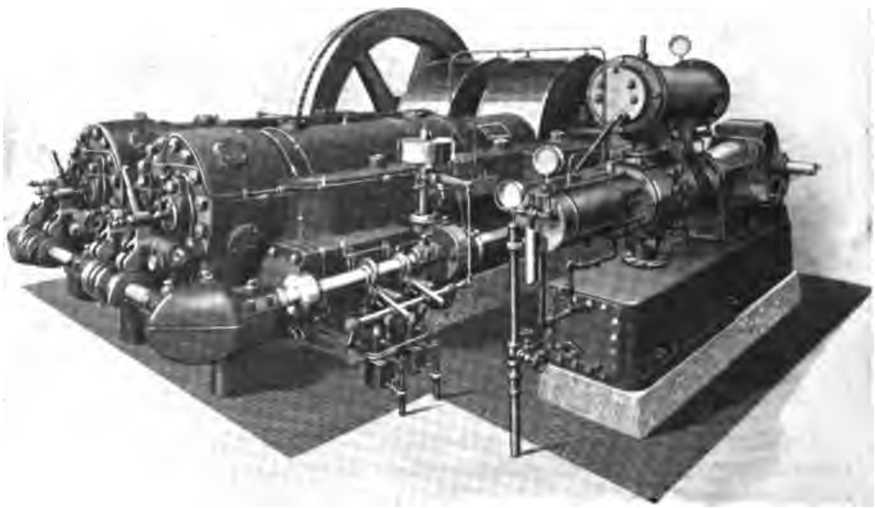


FIG. 59.—De La Vergne Diesel engine and air compressor.

imately one-seventh that of the piston. To avoid carbonization or other troubles with the air compressor valves piping, etc., it is highly important that the cooling effect of the water jackets and of the intercoolers be amply provided for.

Brake or actual H.P.—To ascertain the capacity of an existing Diesel engine the following formula can be used for average conditions.

1. Four-cycle single-acting Diesel engine,

$$N=\frac{F\times s\times n}{810},$$

or if the B.H.P. is known, then the dimension of the cylinder can be found thus,

$$F\times s=\frac{N\times 810}{n}.$$

2. Two-cycle single-acting Diesel engines,

$$N=\frac{F\times s\times n}{500},$$

and similarly the cylinder dimensions are found,

$$F \times s = \frac{N \times 500}{n},$$

where N = B.H.P.;
n = Revolutions per minute;
F = Piston area in square inches;
s = Piston stroke in feet.

The **camshaft** is made of cold rolled steel having diameter

$$= \frac{D}{5.5},$$

where D = diameter of cylinder.

Flywheels.—The general design and construction of the flywheel of a Diesel engine is seen in Fig. 60. It is usually built in two halves connected by a circular link in the rim and with the hub bolted together, for stationary installations. The peripheral speed for cast iron should not exceed 6000 feet per minute, and for cast steel 8000 feet per minute. The function of the flywheel is to maintain a degree of uniformity of speed within specified limits during each cycle of operation of the engine. Its weight will therefore vary inversely with the number of impulses given per revolution of the crankshaft. With a four-cycle single-acting Diesel engine the flywheel will necessarily be heaviest and as the number of impulses are increased or the impulses per revolution are increased the weight will be decreased to give the same effect. The governor controls the speed of the engine while the flywheel controls the cyclic variation and the degree of unsteadiness from the uniform speed of rotation during each cycle. The twisting moment diagrams, Fig. 61 and Fig. 62 (reproduced by permission of the U. S. Bureau of Mines, from the "Diesel Engine Bulletin No. 156" by Herbert Haas), show how the cyclic variation is affected in both two- and four-cycle engines with one or more cylinders and with different setting of the crank pins in relation to each other. The periods in the cycle during which the forces act are denoted by the abscissæ, and the ordinates indicate the forces acting tangentially on the crank pin. The number of cylinders and the different setting of the crank pins are shown. The shaded areas in the diagram represent the excess of power developed during periods of maximum work which is periodically stored in the flywheel to be given off again by it during the negative period. The area shown between the base line and M represents the mean effort of the crank pin. The six- and eight-cylinder engines, two-cycle type, are shown with a setting by which two impulses are transmitted to the crankshaft simultaneously, which correspondingly increases the excess work to be stored in the flywheel which then is proportionately heavier.

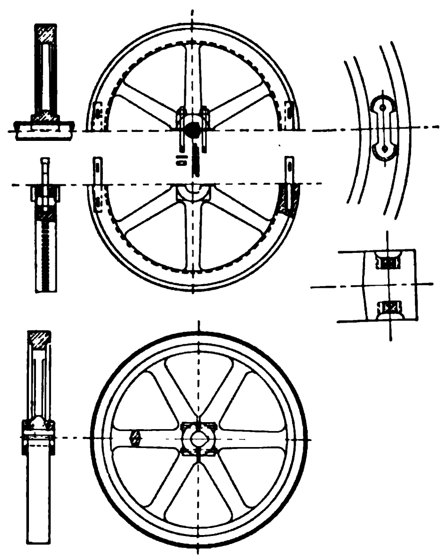


Fig. 60.—Flywheel design and construction.

$$T = \frac{V \text{ Max.} - V \text{ Min.}}{V \text{ Average}},$$

where T = Degree of unsteadiness;
V Max. = Maximum velocity of shaft during cycle;
V Min. = Minimum velocity of shaft during cycle;
V Avg. = Average velocity of shaft during cycle.

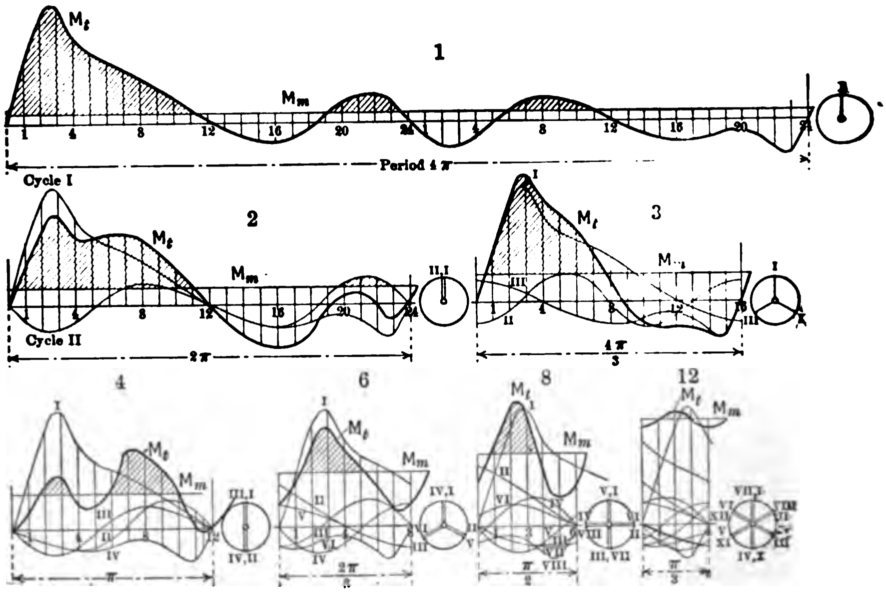


FIG. 61.—Twisting movement diagram, four cycle.

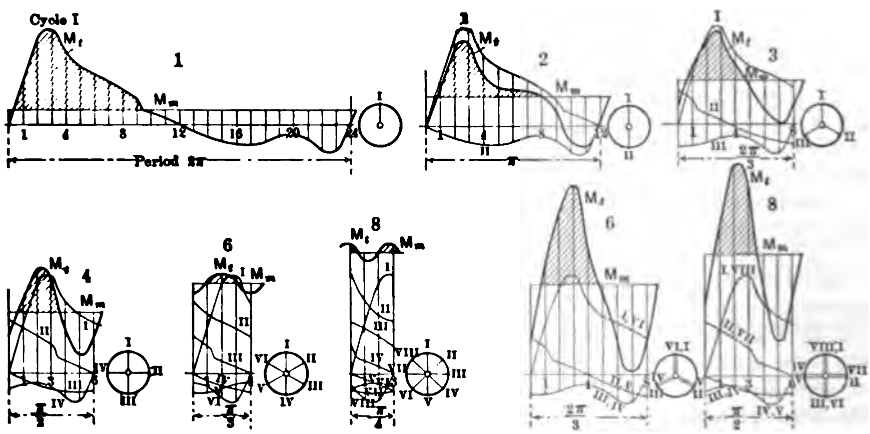


FIG. 62.—Twisting movement diagram, two cycle.

The value of T may be taken as follows:

For factory use	1 : 30 to 1 : 40
For D.C. Generators belt-driven	1 : 70 to 1 : 80
For A.C. Generators belt-driven	1 : 125 to 1 : 150
For A.C. Generators direct connected	1 : 175 to 1 : 200

The weight of the flywheel, neglecting that of the hub and arms of the wheel, may be found by the following:

$$W = C\frac{N}{D^2 \times T \times n^3},$$

where W = Weight of rim in tons (2000 pounds);
D = Diameter of rim in feet at center of gravity;
n = Revolutions per minute;
N = Actual or B.H.P.;
C = Constant.

The values of C given by Güldner are:

C = 712,000 for four-cycle single-acting with impulse each 720°
= 312,000 when the impulse is each 360°
= 178,000 when the impulse is each 240°
= 44,500 when the impulse is each 180°.

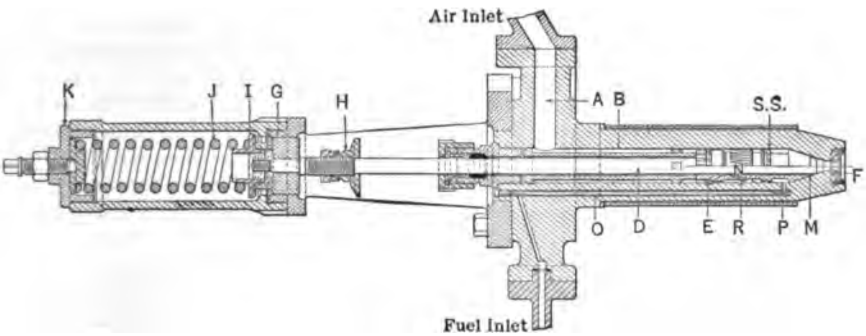


FIG. 63.—McIntosh & Seymour spray valve. (*A*) Air inlet passage. (*B*) Air chamber. (*D*) Fuel inlet valve. (*E*) Air passage. (*F*) Inlet nozzle. (*H*) Collar on valve stem. (*I*) and (*K*) Flanges. (*J*) Valve spring. (*M*) and (*N*) Expanding air passages. (*O*) Fuel inlet passage. (*P*) Annular space for fuel. (*R*) Parts for fuel passage. (*S*) Slotted passages on periphery of atomizer.

Operation of an air compressor of proper size for furnishing injection and starting air is included in this formula.

Sprayers.—The fuel-injection valve or the sprayer or pulverizer is one of the most important features of a Diesel engine. Three different methods of fuel injection are in use in practically all types: (*a*) "solid injection" of the fuel into the combustion space, that is, without air blast, the fuel being forced into the cylinder under great pressure (about 4000 pounds per square inch) as in the Vickers Engine (McKechnie's patented system), also the De La Vergne, the Ruston and the Worthington (vertical stationary type), all of which are described in detail or illustrated hereafter; (*b*) air-blast injection where the fuel meets a blast of air compressed to about 1000 or 1200 pounds at the sprayer and both fuel and air are injected together simultaneously into the combustion space, thus thoroughly pulverizing or spraying the particles of hydrocarbon or vapor. The chief types of this system are (1) the Hesselman design, first employed in the Polar Swedish Diesel Engine and made in the United States by the McIntosh & Seymour Corporation, and illustrated at Fig. 63; (2) The Lietzenmayer or "open" type found in the Dingler, Koerting and other European engines, and in the United States in Snow

Horizontal Diesel Engine and Allis-Chalmers illustrated in Fig. 64. (3) The Deutz sprayer provided with two fuel inlet passages connected to two different fuel supply pumps and suitable for using heavier crude oils and tar oils is shown at Fig. 65. (*c*) The Sabathé fuel-injection valve where two distinct phases of fuel injection are used, the first occurring when the piston is at or near the inner dead center and the second later, is shown at Fig. 66. The chief functions of the sprayer are: (1) that of a valve to introduce the fuel into the combustion space at the correct moment, and (2) that of a sprayer to divide the fuel into minute particles. Ideal fuel injection requires velocity of the injection proportional to the speed of the piston, the atomization of the particles of fuel allowing their maximum surface to be exposed to and combined with the oxygen.[1]

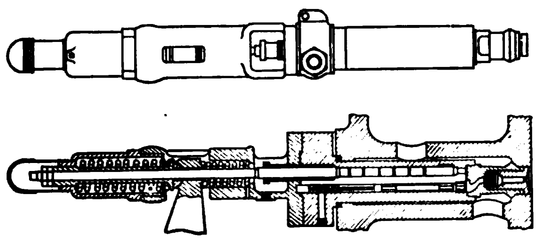


Fig. 64.—Snow sprayer.

Solid injection of fuel is one of the latest developments in the Diesel engine industry. The attention, upkeep and other disadvantageous features of the air compressor operating at 1000 to 1200 pounds pressure are eliminated, as is also the power (about 8 to 10 per cent) absorbed by the compressor itself. The fuel consumption of this type, as will be observed from the table of tests, is approximately the same as that with the air-blast injection. That is, the power absorbed by the compressor being eliminated, the fuel consumption is reduced in the same ratio. In some types, however, the combustion, especially with heavier grades of fuel, may not be as perfect as with the air-blast type.

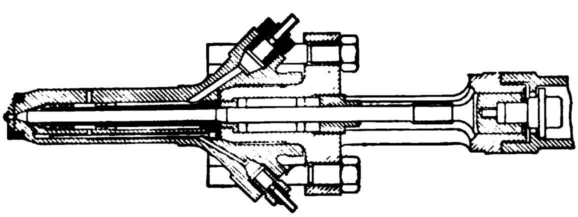


Fig. 65.—Deutz sprayer.

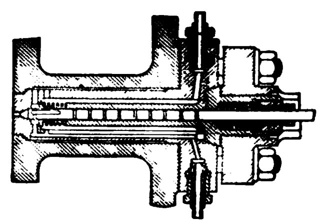


Fig. 66.—Sabathé sprayer.

Nevertheless among the lowest records of fuel consumption will be found those with the solid injection type.

The Vickers system (McKechnie's patent). This fundamental and pioneer system of solid injection type, has the charge of fuel first pumped into a reservoir forming an accumulator which consists of an oval steel tube. The pressure at which the fuel is stored therein is approximately 4000 pounds per square inch. When the spray valve is mechanically opened at the proper period of the cycle the fuel is discharged into the combustion space in a spray of exceedingly fine character which instantly ignites with a lower compression pressure than is necessary with the air blast, because the cooling effect of the injection air entering at 1000 to 1200 pounds and expanding to approximately 500 pounds is eliminated. The nozzle through which the spray enters is provided with a number of fine holes about $\frac{2}{100}$ inch diameter. With the multi-cylinder type

[1] Full and detailed description of Diesel engine sprayers, by the author, will be found in "Motorship" of May, July, and September, 1918.

the accumulator is made of a long pipe from which a smaller pipe connection is made to the spray valve on each cylinder. The fuel supply to the accumulator in this case is furnished by one or two supply pumps only. J. L. Chalnor [1] refers to 100 H.P. per cylinder Vickers engine as having spray nozzles with five holes each of 0.018-inch bore. Messrs. Vickers claim advantages for their system in addition to those mentioned as (*a*) saving in weight (in a 600 H.P. engine for instance, this reduction is approximately 5000 pounds), (*b*) saving in space, of approximately 3 feet in the over-all length, (*c*) reduced cost of production by eliminating the compressor and connections, (*d*) lower fuel consumption, as 0.38 pound per B.H.P. has been recorded with their design in ordinary official trials, (*e*) less attention required and lower cost of up-keep and (*f*) less air consumed for starting purposes.

De La Vergne solid injection of fuel design is shown in Fig. 67. In this arrangement two sprayers are employed and are placed directly opposite each other. The vaporized fuel sprays meet in the center of the combustion space which is situated in the center

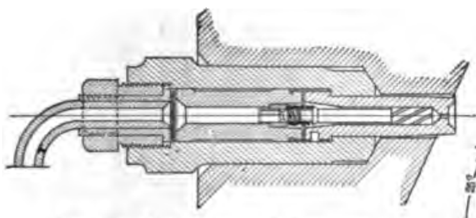


FIG. 67.—De La Vergne S. I. sprayer.

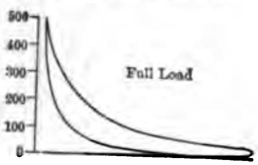


FIG. 68.—Indicator diagram De La Vergne S. I.

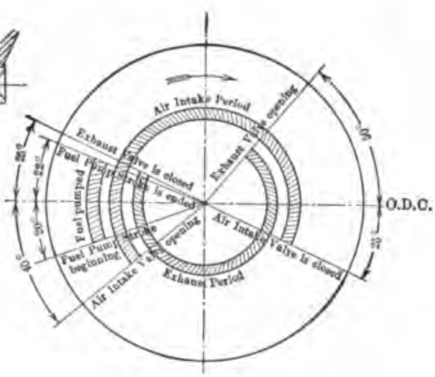


FIG. 69.—Diagram of valve movements De La Vergne S. I.

beyond the position of travel of the piston. The sprays impinging or colliding with each other tend to form a highly atomized mass of fog or vapor, and the air rushing into the vapor forced by the return stroke of the piston produces a turbulence and thorough mixture which is highly inflammable, easily becoming ignited with a compression pressure of 350 pounds per square inch, without other means of heat being required. The fuel is furnished direct to the sprayers by a fuel supply pump for each cylinder. Regulation of speed is effected by opening a by-pass valve so arranged as to vary the period of the spray valve opening. At lighter loads the beginning of the spray is retarded and the point at which the spraying is completed is cut off or hastened. The fuel consumption and other particulars are shown in the table of tests and the periods in the cycle of valve movements are shown in the diagram, Fig. 68. An indicator diagram is reproduced in Fig. 69.

The Ruston and Hornsby sprayer which is employed on their 1915 type of high-compression solid-injection engine, having a compression pressure of 420 pounds is shown in Fig. 70.[2] In this design for tar oils a pilot ignition is arranged in which about

[1] Motorship, N. Y., Feb., 1921.

[2] Extracted by permission from the paper of Mr. F. H. Livens, Inst. of Mechanical Engineers, July, 1920.

5 per cent of lighter oil is first injected into the combustion space followed by the injection of the heavier crude or tar oil. The method of operation is shown by the sectional view. The atomizing of the fuel is effected by forcibly compelling the liquid fuel to lift from its seat the spring-loaded needle inlet valve which closes the opening leading to the injection nozzle. This action is due to the motion of the steep cam actuating the fuel supply pump plunger. The pilot oil is discharged by a needle valve placed

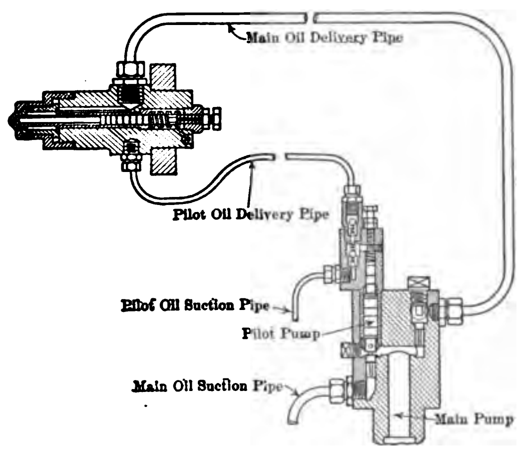


FIG. 70.—Ruston & Hornsby sprayer.

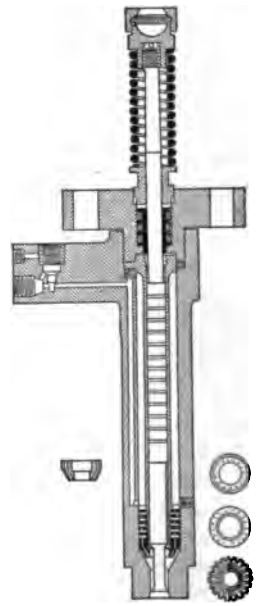


FIG. 71.—Burmeister & Wain sprayer.

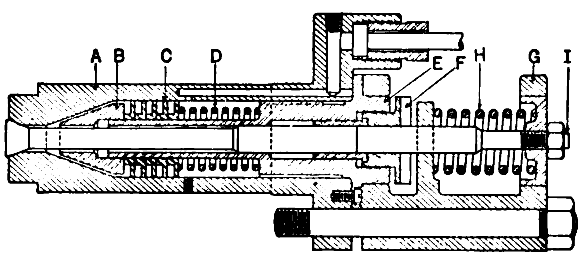


FIG. 72.—Craig sprayer. (*a*) Spray valve body. (*b*) Stop. (*c*) Perforated atomizer plates. (*d*) Spring holding plates against (*b*). (*e*) Valve guide tube. (*f*) Stuffing-box. (*g*) Projection holding tube in place. (*h*) Valve spring. (*i*) Spray valve, opening outwards.

inside the main inlet valve which is made hollow to receive same. The pilot oil pump is actuated by the impulse of the fluid acting on a stepped plunger placed on the main fuel pump, thus precedence of this injection is perfectly secured.

The Burmeister & Wain sprayer, shown in Fig. 71, unlike the other types referred to, has the valve itself opening outwards. This special feature of this design, which is also found in the Craig engine and in one or two others, is so arranged as to thoroughly distribute the fuel inlet spray throughout the whole volume of the combustion space

and equalize the temperature of the gases and avoid unequal heating of the piston crown piece. The Craig sprayer made for the James Craig Diesel Engine where the valve opens outwards is shown in Fig. 72.

The Hvid-Brons spraying device is shown in Fig. 73. It differs from the Diesel sprayer in that the fuel is first delivered to the cup placed below the fuel injection valve during the air suction period. As the compression proceeds, the air at increasing pressure is forced through the small holes drilled through the sides of the cup at *C* and the increasing temperature due to the friction of the air passing through these small apertures, together with the temperature caused by compression to about 450

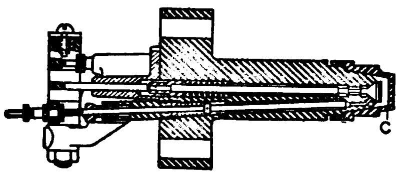


Fig. 73.—Hvid-Brons sprayer.

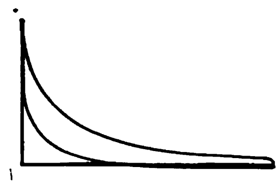


Fig. 74.—Hvid-Brons indicator card.

pounds is sufficient to cause ignition of the vapor first in the cup and afterwards in the whole mass of vapor in the combustion space. An indicator diagram taken from the Hvid-Brons engine is shown in Fig. 74.

Turbulence.—The two features for Diesel engine tar-oil spraying devices, (*a*) atomization, (*b*) turbulence, are described in detail by P. H. Smith.[1] The former term refers to the degree of fineness of the spray at the moment it leaves the flame plate or nozzle, while the latter term refers to the degree of swirling which occurs in the combustion space as the spray enters and which produces thorough and intimate mixture of fuel and air.

Governing.—With stationary installations the system most generally used for the regulation of the speed of the engine is that accomplished by varying the amount of fuel delivered to the sprayer by altering the point in the stroke of the pump plunger at which the suction or cut-off valve is allowed to come in contact with its seat. Thus at full load with the valve seating earlier a greater amount of fuel is delivered to the sprayer and at lighter loads with the valve seating later, less fuel (in accordance with the load on the engine) is delivered to the sprayer. Such an arrangement is shown in Fig. 75. The pump plunger is operated with constant length of stroke, actuated by eccentric or by cam motion, and the governor directly controls the suction or cut-off valve.

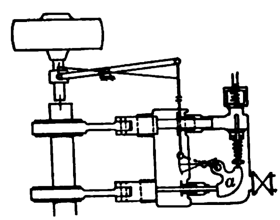


Fig. 75.—Governing arrangement (pump suction valve).

The fuel pump with Diesel engines is of massive proportions as the plunger operates against a pressure of 600 to 1000 pounds air pressure which meets the fuel supply at the sprayer (except in those designs having the "open" type nozzle where only the resistance due to friction in pipes, etc., has to be overcome). The steel plunger passes through a carefully packed gland for which asbestos cord packing greased with tallow and graphite is often used. The valves are of bronze or steel with conical seatings held in position by springs and so situated as to be readily accessible for cleaning or re-grinding into their seats. The displacement of the plunger is greater than necessary, frequently being equivalent to four times the actual fuel supply required. In this way possible leakage or other improper working conditions are taken care of, allowance for temporary

[1] Paper read before Diesel Engine Users Association, London, England, 1918.

overloads is made and the volumetric efficiency of the pump, only about 70 per cent, is provided for. Some engines have one pump for each cylinder, others have the fuel conducted to the cylinders through a distributor supplied by one pump only for two or more cylinders.

Safety valve.—All Diesel engine cylinders should be equipped with a safety valve so as to relieve undesirable high pressures which may be developed. It should open at about 570 pounds pressure per square inch.

Air tank for injection air should have a capacity of approximately 0.035 cubic foot per B.H.P. of engine. The air tanks for starting purposes should have a total capacity of 0.2 to 0.35 cubic foot per B.H.P. At least two tanks are usually installed.

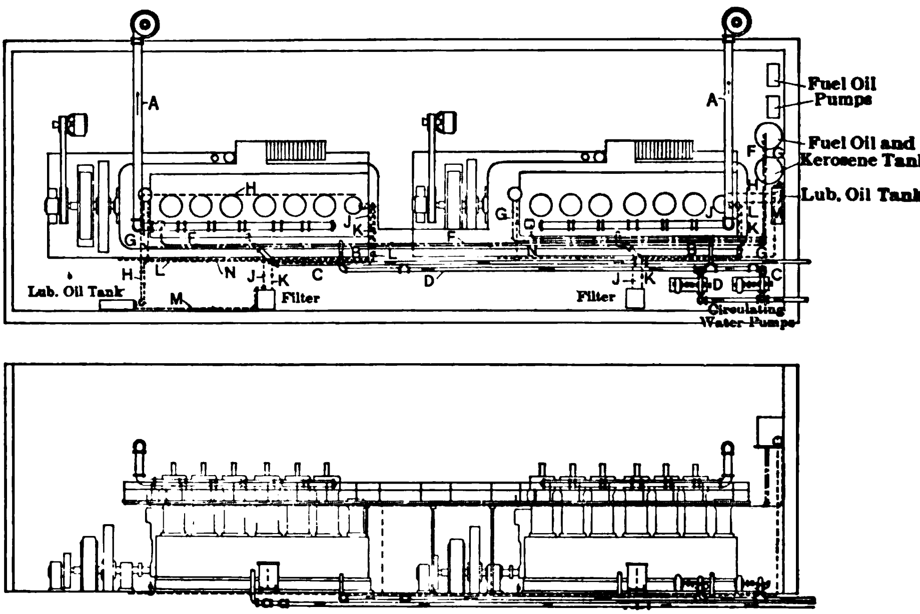


FIG. 76—Two 1000 B.H.P. vertical Diesel installations. (*A*) Exhaust pipe, cast iron, 12 inches diameter. (*B*) Cooling water inlet w. i. 4 inches diameter. (*C*) Cooling water outlet c. i. 6 inches diameter. (*D*) Water discharge from pumps 6 inches diameter. (*E*) Suction to water pumps 6 inches diameter. (*F*) Fuel supply piping to pumps 2 inches diameter. (*G*) Kerosene piping to pumps 1¼ inches diameter. (*H*) Lubricating oil piping from tank to engines 1¼ inches diameter. (*J*) Lubricating oil piping to filter ¾ inch diameter. (*K*) Lubricating oil piping filter to pump 1 inch diameter. (*L*) Lubricating oil piping pump to tank ¾ inch diameter. (*M*) Piping to lubricant overflow 1 inch diameter. (*N*) Lubricating oil drain from engine 1¼ inch diameter.

INSTALLATION, OPERATION AND CORRECTION OF STATIONARY TYPE DIESEL ENGINES

Preliminary.—The engine room correctly designed and arranged allows ample space around each engine erected in it both for proper attendance and for the removal of any part of the engine that may require inspection or repairs. Where it is necessary with the vertical type, sufficient head room should be provided for withdrawing the piston and connecting rod from above. A traveling crane overhead is advantageous both during installation and when necessity for repair arises. The engine room should be well lighted and ventilated, and free from injurious gases, the floor should be of dust proof material and the engine room should be properly heated especi-

ally in colder climates so as to prevent freezing of the circulating water pipes or passages of the engine, etc. A representative installation of stationary Diesel engines is shown in Fig. 76. The foundation for the engine is built of the best concrete, a mixture for which can be composed of one part Portland cement and six to seven parts of sand and broken stone. For horizontal engines the weight of foundation should not be less than 2000 pounds per B.H.P., for single cylinder types, and slightly less per B.H.P. for twin-cylinder engines. With vertical multi-cylinder engines this weight can be decreased slightly. Güldner advises weight of 1750 pounds with two-cylinder vertical engine and 1300 pounds per B.H.P. with three-cylinder types and 1100 pounds with a four-cylinder engine. The depth of the foundation should not be less than $5D$ when D equals diameter of cylinder. The above dimensions are for use when the foundation is built on solid ground. Where wet ground or quicksand, etc., is encountered piling or other special arrangements must be made to make the ground the equivalent of solid ground before the building of the foundation is commenced. Usually the engine foundation is thoroughly insulated from the foundation of the building or other foundations near it so as to prevent vibrations being transmitted from the engine foundation to them.

Exhaust pipes.—Arrangements of these pipes are shown at Fig. 76 and Fig. 105. With the horizontal type that part of the piping which is above the floor line is usually water jacketed to prevent radiation of heat to the engine room. With the vertical type the manifold and sometimes other connections are also water jacketed. Between the engine valve box or outlet and the silencer the exhaust pipe should have an area of 1.15 to 1.3 times the area of the exhaust valve. From the silencer to the atmosphere with four-cycle engines the size of piping may be slightly decreased but with two-cycle type the area of the exhaust pipe should be as large as possible. Arrangements should be made to allow for the expansion and contraction of the exhaust pipe near the engine and where it becomes greatly heated in operation. A separate exhaust pipe was always formerly recommended for each combustion space in a multi-cylinder engine, but with present practice the separate exhausts have been satisfactorily replaced by one pipe for all cylinders arranged as shown in Fig. 76. In every installation a test cock should be inserted in the piping of each cylinder so that the color, etc., of the exhaust from each cylinder can be tested whenever required.

Air-inlet pipes should be of the following sizes for four-cycle engines,

$$f=\frac{F\times c}{120}.$$

For two-cycle engines:

$$f=\frac{F\times c}{60},$$

when f = area of inlet pipes in square inches;
F = area of piston in square inches;
c = piston speed in feet per second.

Cooling arrangements.—Reference to the heat balance of a Diesel engine shows that about 33 per cent of the total B.t.u. supplied in the fuel is carried away by the cooling water, and the importance of proper arrangements to accomplish this efficiently is evident. The different methods of cooling are: (*a*) Continuous water supply passing through the cooling jackets and then going to waste. (*b*) Re-cooling the water (where it is scarce or expensive but of good quality) by means of an open screen type of cooling tower, of simple construction, or other similar apparatus which will accomplish the same result. A considerable amount (one-half to one gallon per B.H.P. hour) of make-up

water will have to be added and this should be of such quality as to have no tendency to form scale in the passages of the engine. (*c*) Use of clean sea water pumped so as to allow rapid circulation through the passages of the engine. (*d*) Enclosed cooling system, an arrangement of which, as recommended by the De La Vergne Machine Company, is shown in Fig. 77. This system is necessary where only hard, scale-forming or otherwise poor cooling water is available. All the cooling piping and engine jackets are first filled with soft water. The heated water, after discharge through a visible outlet into the sump tank, is pumped through a series of cooling coils up to the overhead tank. The coils are showered outside with any available water and only the cooling water of suitable composition circulates within the engine passages. With this system only a slight amount of make-up rain or soft water is required and where necessary the outside cooling water can itself be recooled in an open cooling tower. Scale formed in the cooling jackets of the cylinder, head or other parts is very injurious; it prevents proper cooling effect and is frequently the cause of cylinder head cracking and other troubles. If scale is found to have been formed it can be removed by filling the passages with a mixture of one-half water and one-half muriatic acid and allowing them to remain filled. After effervescence ceases more acid should be added and if no further action is seen this indicates that the scale has been removed. The amount of cooling water necessary will vary with different designs of engines. The outlet water temperature as recommended by some makers should be about 120° F. and with others may be as high as 160° F. Usually with the initial temperature of the water at 50° F. and a discharge temperature less than 160° F., with a four-cycle engine, 4 to 5 gallons per B.H.P. hour is sufficient. The outlet temperature with a two-cycle engine should not exceed 120°, and then at least 8 gallons per B.H.P. hour should be furnished. All cooling-water devices should be of ample capacity so as to allow additional cooling medium in emergencies. With all arrangements the cooling water should flow from a tank, placed 20 feet or more above the engine, to which the cooling water is first supplied and from which it gravitates to the various parts of the engine. The method of connecting the piping varies in different designs. In some, the cooling water is first passed through the jackets and intercoolers and aftercooler of the air compressor, then through the main cylinder jacket and then the cylinder head; in others, separate water connections are employed with branches to each cylinder as well as to the compressor.

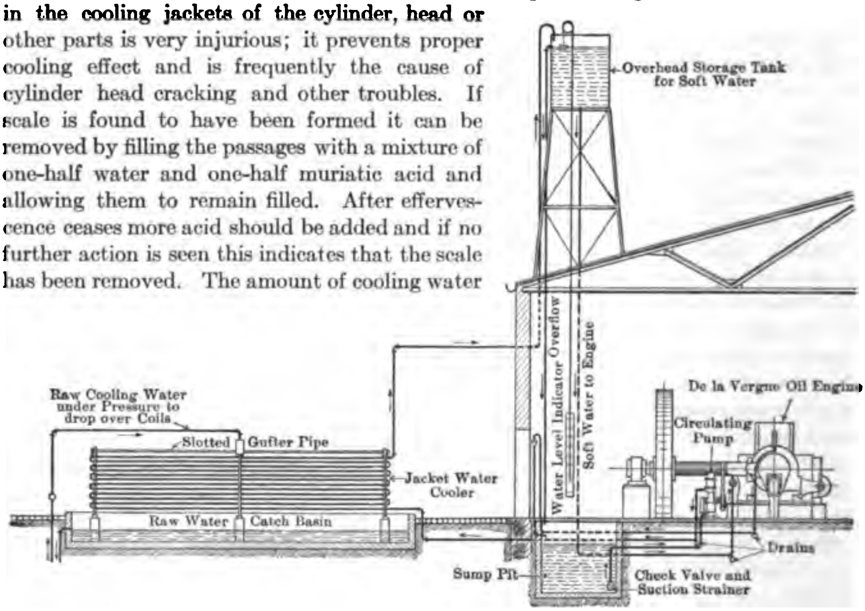


Fig. 77.—De La Vergne enclosed cooling system.

With any system the flow of water from each outlet should always be visible to the attendant and thermometers should be placed wherever necessary so that it will be easy to note that proper temperatures are always maintained in operation. The cooling water should never be cut off immediately after the engine is stopped. Circulation should continue until the parts of the engine have cooled off. Cold water should not be turned on suddenly to an engine already heated. In frosty weather where the engine room is insufficiently heated, water jackets, etc., should be drained to prevent freezing when the engine is standing idle.

Silencer.—A cast-iron silencer having a cubical area of 6 to 8 times that of the piston displacement is used where complete silencing is unnecessary. When the noise of the exhaust is objectionable a silencing arrangement, as shown in Fig. 78, can be used.

Air-inlet silencer consisting of wrought-iron pipe with two rows of slots cut in the end is shown in Fig. 105.

Operation.—Diesel engines probably require more careful and skilled attendance than any other prime mover. The durability and low cost of maintenance are dependent on this treatment. The attendant should also be capable of remedying any defect as soon as it is shown to exist. To develop its maximum efficiency a Diesel engine must be kept in the best possible working condition.

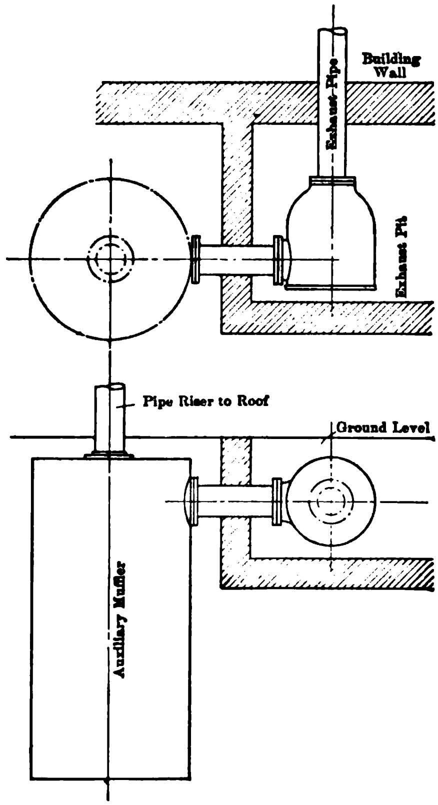


FIG. 78.—Concrete pit silencer.

Starting preparation.—If any repairs have been made since it was previously operated, the flywheel should be turned over once or twice by auxiliary power or by hand to ascertain that all moving parts are clear and that no obstruction can prevent its proper operation. The following remarks must be taken as only general instructions. The attendant should first carefully study the specific instructions which accompany the engine. These are supplied by all builders and relate to their particular design. In a general way the following method of starting *stationary* engines may be followed.

1. Fill all lubricating devices with the *proper* lubricant as hereafter referred to and exercise great care that each lubricating device is operating and is in proper working order, so that all moving parts have a supply of lubricant before the engine is started or as soon as it starts.

2. Examine air-pressure tanks and see that they are charged to the proper pressure (200 to 300 pounds) or as recommended by the engine builders.

3. Test the cooling-water supply and see that the cooling medium is properly furnished to all parts requiring to be cooled. Where necessary, prime the circulating water pump and see that all valves for the discharge of cooling water are open or properly adjusted.

4. Turn the crankshaft so that the crank pin is about 30° after the inner dead center.

5. Place the exhaust cam on the low-compression pressure side or manipulate such parts as are required to obtain the same effect.

6. Ascertain that the air injection valves are in proper operating condition; open wide the air inlet to the low-pressure side of the air compressor.

Starting proper.—(*a*) Test the fuel supply to insure that the fuel connections are filled with oil, by hand operation of fuel supply pump, until fuel flows through the by-pass.

(*b*) Open all valves in the starting air line between air tank and engine, also all valves in the air line between compressor and tank.

(*c*) When the engine has attained sufficient speed the starting valve lever is put out of action and the valve on the starting air tank closed, the injection air valve being left wide open.

(*d*) The fuel supply can be fully opened. Where heavy and light fuels are used,

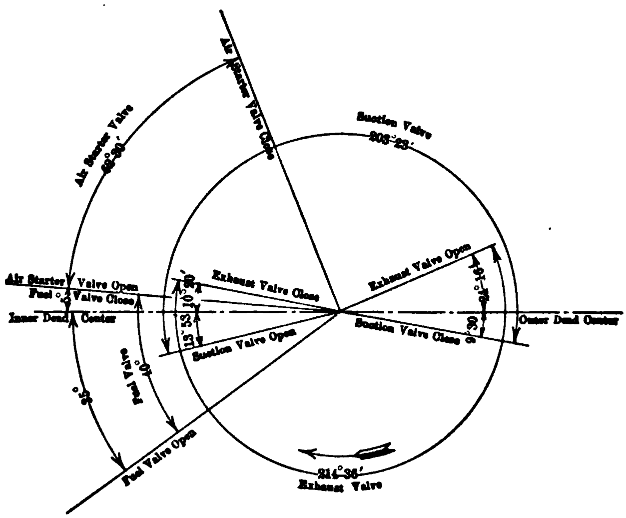


FIG. 79.—Representative Diesel valve setting diagram.

the heavy fuel can now be brought into action. (Heavy fuel will probably require pre-heating to about 120° F.)

Operation.—An engine running in good condition will have absolutely invisible exhaust gases, when working with load, and possibly slightly bluish-white colored exhaust gases at light loads. There will be no knocking or hammering and the engine will run smoothly and evenly.

Stopping.—1. Shut off the fuel supply to the fuel-injection valve.

2. Close the suction air valve to the high-pressure stage of air compressor.

3. Close the valves at the air tanks to avoid loss of air.

4. Close all lubricating devices to prevent waste of lubricant.

5. When the engine has had sufficient time to become properly cooled, shut off the cooling-water supply.

6. If there is danger of freezing, drain the water from jackets, etc.

General remarks.—(*a*) Allow the pressure in the starting air tanks to be brought up to normal as quickly as possible.

(*b*) The pressure of the injection air should be correct. Too low injection air pressure may cause poor combustion in the cylinder or late ignition. Too high injection air pressure may cause too early ignition and possibly slight knocking.

(*c*) With two-cycle types it is very necessary to observe that the scavenging air pressure is always maintained at approximately four pounds or at that pressure recommended by the builders.

(*d*) With water- or oil-cooled piston the attendant should be sure that the cooling medium circulates properly and starts to flow immediately the engine is in operation. Improper cooling of piston will result in carbonizing of lubricant on piston and piston rings.

(*e*) The fuel-injection valve stem can be packed with metallic packing or with ½ inch round high-pressure asbestos packing cut in rings and thoroughly impregnated with graphite. When the engine is stopped a small amount of kerosene can be forced around the valve stem to clean the valve and facilitate starting.

(*f*) The correct setting of the air and exhaust valves and the periods of fuel injection with a representative Diesel engine are shown on the diagram, Fig. 79.

Improper operation at starting may be due to faulty working of the starting valve and examination of this valve will be necessary. Leakage by the piston rings or by the inlet or exhaust valves may cause loss of compression pressure and then the temperature of compression may be too low to cause ignition. Failure of proper fuel supply may also cause faulty ignition. Sometimes an air pocket in some part of the fuel supply system may be the cause. In other cases leakage of the suction or discharge valves of the fuel-supply pump has been the cause of the trouble. Careful examination of air-supply and fuel-supply mechanism in detail will then be necessary. Fuel must *never* be pumped by hand when the engine is in *operation*.

If leakage of compression pressure is suspected and cannot readily be detected the indicator should be attached and a few diagrams taken. If the pressure is below the normal, careful examination of all valves, piston, etc., must be made to ascertain the cause of leakage. If the pressures are correct the diagram should appear similar to that shown in Fig. 94. A light spring diagram as shown in Fig. 80, can if necessary be taken, as leakage of the valves is more readily detected with it.

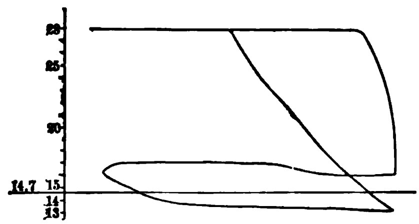


Fig. 80.—Light spring diagram.

Knocking or uneven running of the engine may be due to incorrect timing of the fuel injection; that is, the fuel and spray may reach the combustion space too early and ignition begin too soon in the cycle. It may also be due to loose main bearings or connecting-rod bearings which may require adjustment.

Air compressors should have the least possible amount of lubrication and that of the right composition as hereafter referred to. Trouble with air compressors most frequently results from too much lubricating oil. The low-stage compression pressure should not exceed 90 pounds per square inch. With this pressure and with the suction valves on the high-pressure stage open wide, the injection pressure will be about 1000 pounds. Throttling the suction to the low-pressure cylinder should be avoided; otherwise a vacuum will be created which will result in more lubricating oil being drawn into the compressor cylinder.

Lubricants.—The main cylinder and piston should be lubricated with a light mineral oil having a viscosity of 300° to 750° Saybolt at 100° F., having a high flash point (about 370° F.) and free from animal matter. The air-compressor cylinder should

have little or no lubrication. When any lubricant is applied it should be similar to that used on the main piston.

The parallel operation of alternators direct connected to internal-combustion engines is a subject that has been widely discussed everywhere.[1] The requirements of manufacturers of electrical apparatus for proper paralleling are that the total flywheel effect should be such that the angular deviation from the uniform speed of rotation within the cycle does not exceed 3½ electrical degrees. A mechanical degree is equivalent to an electrical degree divided by half the number of poles of the alternator. For instance, with an alternator having 48 poles, 6 electrical degrees would be equivalent to 0.25 mechanical degree.

Everest[2] gives the permissible limit of speed irregularity, thus:

$$\text{Degree of irregularity} = \frac{K}{6 \times (\text{number of poles})},$$

where K = number of impulses per revolution.

The flywheel effect to avoid resonance in foot-tons of stored energy at normal speed per one K. W. equals

$$\frac{1.3 \times \text{poles} \times (\text{strokes per engine cycle})^2}{\text{R.P.M.}}$$

For stationary installations the great advantage of the Diesel engine lies in its unsurpassed high thermal efficiency and fuel economy and its ability to operate with cheap and low grades of fuels having high boiling points. This result is achieved with all sizes of engines. Being a self-contained unit, its only auxiliary is the air compressor for furnishing starting air. It occupies less space than other prime movers, its fuel is easily transported and handled and can be stored underground in a minimum of space. The absence of ashes and smoke make it cleanly, and the odorless and colorless exhaust from it can be almost entirely silenced wherever necessary. Full power can be instantly developed after starting from cold, and the fuel consumption ceases as the engine is stopped; thus there are not the standby losses incidental to steam plants. Its reliability of operation, if properly designed and constructed and given proper attention, is equivalent to that of any other prime mover.

Table 7 (Herbert Haas) shows the thermal efficiency of different prime movers with continuous full load. The larger figures for fuel consumption refer to small installations and the smaller figures to larger plants equipped with the best machinery.[3]

Table 8 on the following page presents fuel-cost data covering the operation of the prime movers represented in Table 7.

Cost of Fuel

Cost data covering the various types of fuel used in the prime movers represented in Tables 7 and 8 are presented in Table 9, following:

The cost of converting 1,000,000 B.t.u. into work on the basis of 2545 B.t.u = 1 B.H.P. may be found as follows—(Haas):

$$\frac{\text{Cost of 1,000,000 B.t.u.}}{\text{Over-all thermal efficiency of engine}}$$

[1] Parallel Operation of Alternators, Inst. E. E., 1908, Dr. E. Rosenberg; Design of Flywheels, etc., by R. E. Doherty and R. F. Franklin, A.S.M.E., 1920.

[2] Journal Inst. E.E. (London) p. 530, 1912.

[3] Tables 7, 8, 9, and diagrams Figs. 81, 82, 83, are reproduced from Diesel Engine, by H. Haas, by permission of Bureau of Mines.

TABLE 7

Heat Consumption and Thermal Efficiencies of Different Types of Prime Movers at Continuous Full Load

Type of prime mover	Heat consumption per brake horse-power-hour, B.t.u.	Over-all thermal efficiency	Superiority of Diesel engine *
Non-condensing steam engine †	40,000–28,000	6.30– 9.1	5.6 –3.6
Condensing steam engine using superheated steam †	28,000–16,500	9.1 –15.4	3.6 –2.3
Locomobile engine with superheated steam and reheater, condensing †	17,000–15,200	14.9 –16.7	2.4 –2.1
Steam turbine, superheated steam, 200 to 2000 H.P.†	24,000–15,500	10.6 –16.2	3.2 –2.2
Steam turbine, superheated steam, 2000 to 10,000 H.P.†	15,000–14,000	16.2 –18.1	2.2 –1.95
Gas engine without producer	10,400– 9,300	24.4 –27.5	1.33–1.28
Suction gas engine ‡	14,000–11,200	18.1 –22.7	1.95–1.55
Diesel engine	8,000– 7,200	32. –35.3	....

* Figures in this column are to be used as factors with which to multiply values in preceding column.
† Figures include boiler losses. ‡ Figures include producer losses.

TABLE 8

Comparative Cost Data.—Cost of Operation

Type of prime mover	Kind of fuel	Average cost per 1,000,000 B.t.u.	Cost of 1,000,000 B.t.u. effective work	Heat cost per one effective horse-power-hour
		Cents	Cents	Cent
Non-condensing steam engine *	Coal	12	191–132	0.48–0.34
Condensing steam engine using superheated steam *	Coal	12	132–78	.34– .20
Locomobile engine with superheated steam and reheater, condensing *	Coal	12	81–72	.21– .18
Steam turbine, superheated steam, 200 to 2,000 H.P*	Coal and	12	113–74	.29– .19
	anthracite	11	104–68	.27– .17
Steam turbine, superheated steam, 2,000 to 10,000 H.P.*	Coal and	12	74–67	.19– .17
	anthracite	11	68–61	.17– .155
Gas engine without producer	Natural gas coke-oven	15	62–55	.16– .14
	gas or blast furnace gas	7	27	.7
Suction gas engine †	Anthracite	11	61–49	.16– .14
Diesel engine	Petroleum	15–18	56–43	.14– .11

* Figures include boiler losses. † Figures include producer losses.

TABLE 9

Cost of Various Types of Fuel

Kind of fuel	Price of fuel	Heating value per pound	Absolute heat cost per 1,000,000 B.t.u.	Average heat cost per 1,000,000 B.t.u.
		B.t.u.	Cents	Cents
Lignite	$1.00 to $2.50 ton of 2000 pounds	5,000– 9,000	10 –14	12
Bituminous coal	$2.00 to $4.00 ton of 2000 pounds	11,000–14,200	9 –14	12
Anthracite	$2.50 to $4.00 ton of 2000 pounds	14,500	8.6–13.8	11
Fuel oil (petroleum)	$.75 to $2.25 barrel	18,000–19,000	12.5–37.5	15–18
Natural gas	$.10 to $.75 1000 cu. ft.	900– 1,000	11 –75	15
Blast furnace gas	$.05 to $.10 1000 cu. ft.	90	5.5–11	7
Coke-oven gas	$.02 to $.05 1000 cu. ft.	450	4.4–11	7

Cost per B.H.P. hour is:

$$\frac{\text{Cost of 1,000,000 B.t.u.}\times 2545}{\text{Over-all thermal efficiency}\times 1{,}000{,}000}.$$

The heat balance of various prime (movers as prepared by Haas) is reproduced in Fig. 81.

In estimating the cost of generating power the following items must be considered: The thermal efficiency and cost of fuel, the space occupied, the load factor, interest and depreciation, cost of labor and attendance, lubrication and supplies.

The influence of these different items with small Diesel engines is shown clearly in Diagrams Fig. 82 and Fig. 83 here reproduced. Diesel engines with 80 per cent load of 100 and 200 H.P. rating operating industrial plants are referred to. Labor at $3.00 for 8 hours, total installation cost of $100 per B.H.P. for the 100 H.P. and $90 for the 200 H.P. are taken. All costs refer to a unit of 1 H.P. operating 8760 hours per year.

The four-cycle "Busch Sulzer" Diesel engines, as shown in Fig. 84 and Fig. 85, are all built with four cylinders, vertical single-acting. They are designed for heavy duty service. The bed-plate is made in one piece, bored to receive the main-bearing shells. The crankcase is of the enclosed box type, with the cylinder jackets bolted directly to it. The cylinders are made in two pieces, the outer jacket which carries all axial stresses, and the liner, the upper end of which seats on a shoulder in the jacket and thus makes a water-tight joint, the liner being free to expand downward. The upper face has a groove, into which a male part of the head registers. The cylinder heads are made of symmetrical design, and contain pockets for the inlet-air valve, exhaust valve, fuel valve, and air-starting valve, all in a vertical position. The inlet and exhaust valve levers are split to facilitate removal of the valve complete with its cage. The exhaust valve housings are water-cooled. The fuel valve is of the " closed " type and opens upward as shown in Fig. 86. The seats for the fuel inlet, air inlet, and exhaust valves are renewable. The horizontal cam shaft is carried in an enclosed casing

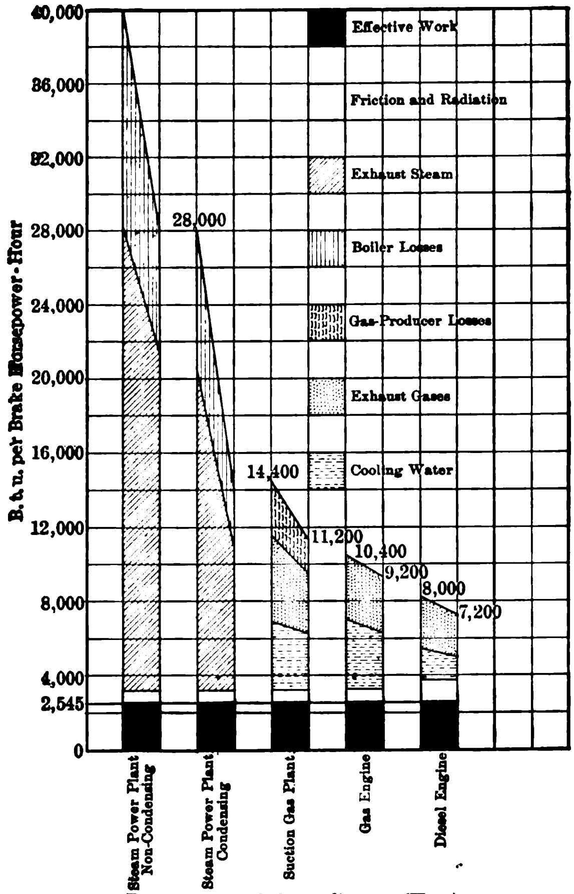


FIG 81.—Heat balance diagram (Haas).

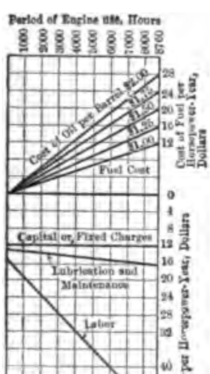


FIG. 82.—Comparative costs of the different items of a 200 H.P. Diesel engine operating at 80% load average.

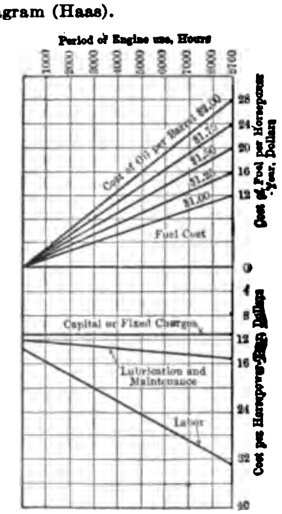


FIG. 83.—Comparative cost of different items of a 100 H.P. Diesel engine operating at 80% load average.

along the top of the cylinders and is actuated from the crankshaft by two sets of helical gears, one at the lower end and the other at the top of the vertical lay shaft, located at the flywheel end of the engine and geared off the crankshaft between the coupling flange and first journal. All gears work in oil, and are enclosed in oil-tight housings. The governor is of the spring-loaded centrifugal type, enclosed and self-lubricating, provided with synchronizing attachment. It is arranged to control the amount of fuel delivered to each cylinder; in the larger sizes it also automatically controls the air-injection pressure and the lift and duration of opening of the fuel needle valve. Safety stop governors prevent overspeeding on the larger sizes. The governor varies the

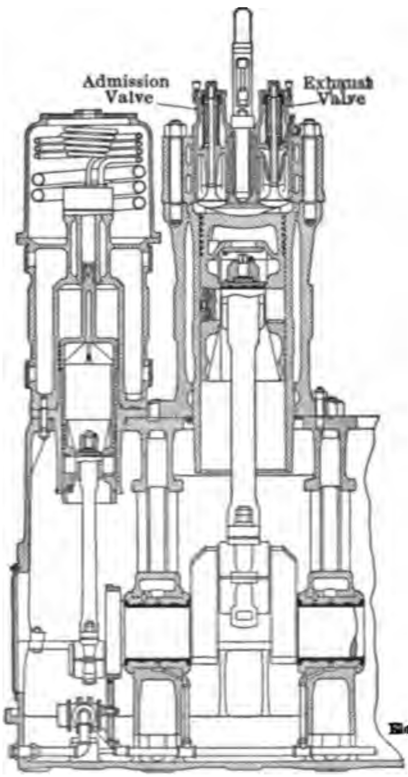


FIG. 84.—Busch-Sulzer four-cycle engine section.

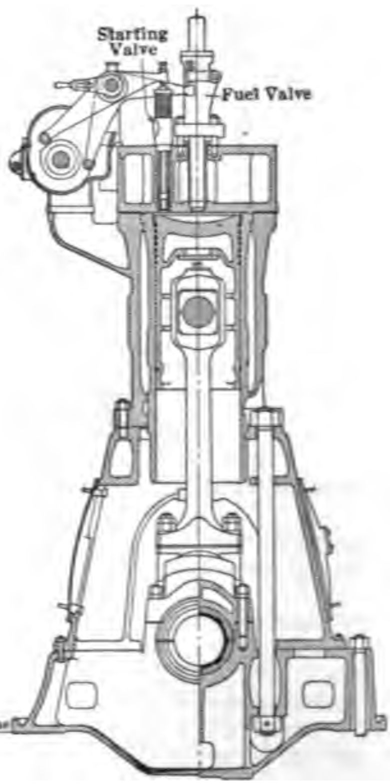


FIG. 85.—Busch-Sulzer four-cycle engine section.

amount of fuel delivered by the fuel pump to each cylinder by controlling the time of seating of the suction valve of the pump in the usual way. On the 520 H.P. engine the pistons are water-cooled by a patented system of telescopic tubes, requiring no swing joints.

The four-throw crankshaft with additional crank for the air compressor is made of solid open-hearth steel forged in one piece with coupling flange at flywheel end. The three-stage air compressor shown in Fig. 87, mounted on the crankcase in line with the working cylinders, is direct driven and is provided with adequate intercoolers and aftercoolers. The compressor valves operate without springs and are of uniform design, mounted in removable cages. A pressure lubricating system is provided, and

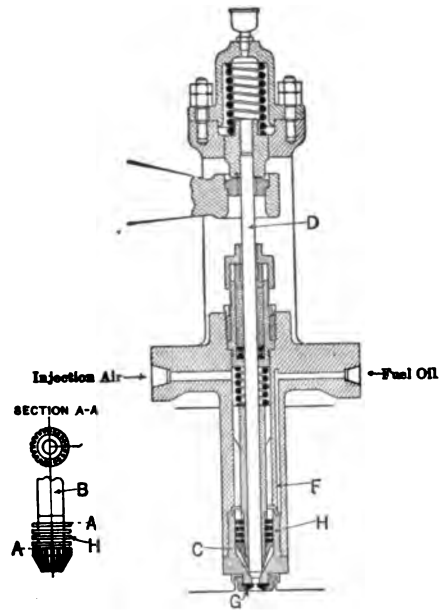


FIG. 86.—Busch-Sulzer sprayer. (*B*) Sleeve holding plates and distance pieces. (*C*) Cone-shaped nut, grooved. (*D*) Fuel inlet valve. (*F*) Annular slot. (*G*) Inlet nozzle. (*H*) Fuel distributor, plate type.

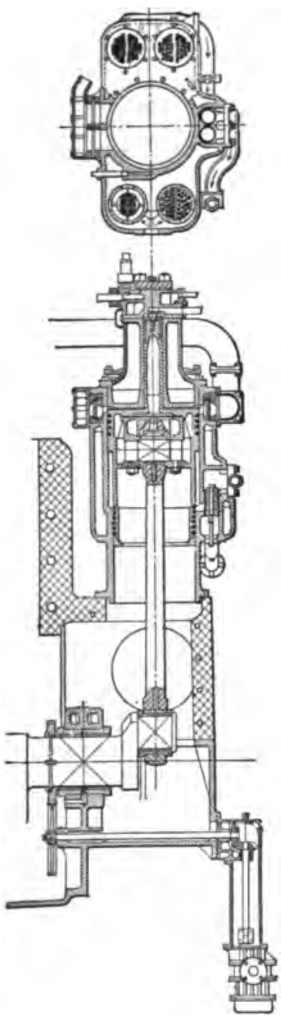


FIG. 87.—Three-stage air compressor (Busch-Sulzer).

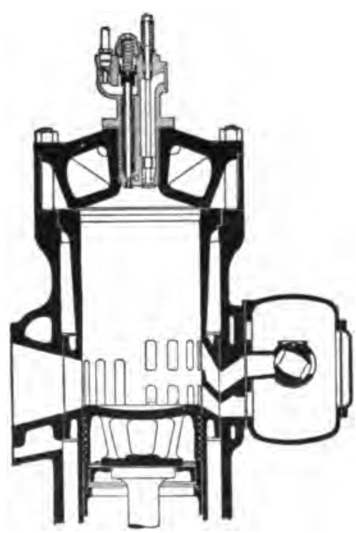


FIG. 88.—Busch-Sulzer two-cycle engine.

lubricates all main bearings, crank pin and piston pin boxes, vertical shaft thrust bearing, and all lower helical gears, with a continuous supply of oil, under pressure. Twin oil filters and tubular coolers are employed. A gear-driven positive displacement pump delivers clean and cooled oil to the system at a pressure of from 10 to 20 pounds per square inch. The cylinders are lubricated by a force-feed oil pump, direct driven from the cam shaft. A reserve of oil in the cam-shaft housing supplies oil to cams, cam rollers, and cam-shaft bearings.

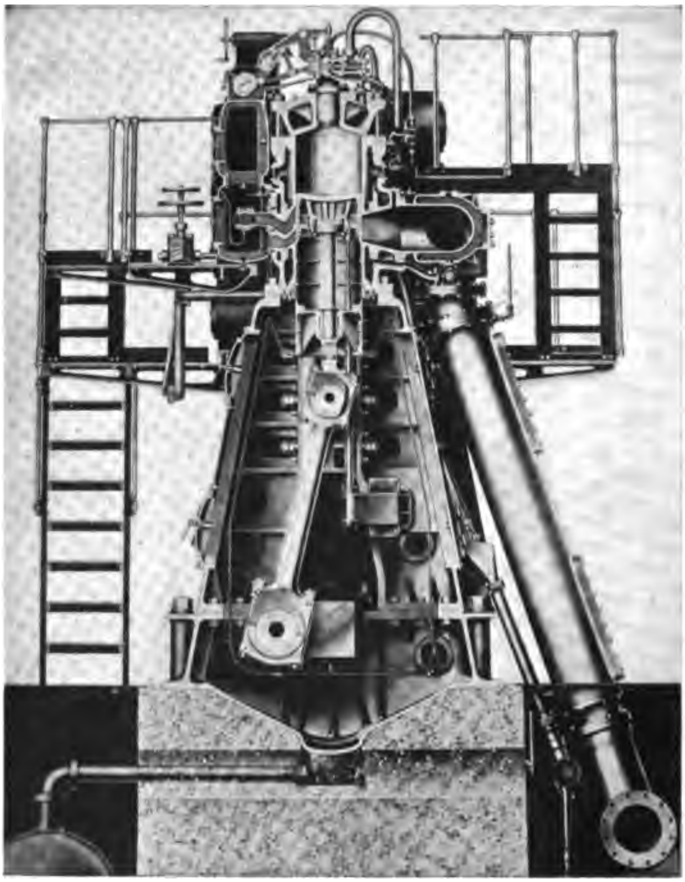


Fig. 89.—Busch-Sulzer two-cycle engine.

The two-cycle "Busch Sulzer" Diesel engines (see Figs. 88 and 89), are of the vertical four- or six-cylinder, single-acting, crosshead type, having an impulse per cylinder per revolution of the crankshaft. They are built for heavy duty, stationary work, or for marine installations, being then directly reversible. The injection-air compressors in all types, are directly driven from cranks which are an extension of the main crankshaft. The scavenging air pumps on some types are directly driven, but for others turbo blowers are furnished to supply the scavenging air. The bedplate is built in sections (with bridges between the two-cylinder units), containing bored seats for the

main bearing shells. The crankcase is oil-and gas-tight, of the enclosed type, built up in sections, is rigidly bolted to the top of the bedplate and carries the crosshead guides; the cylinder jackets are bolted directly to it. The separate liner is provided with slots or ports, in its wall for the admission of the scavenging air, and discharge of the exhaust gases. This construction allows free expansion of both parts. The space between the liner and the jacket constitutes the cooling-water space. The cylinder heads, Fig. 90, are of very simple and symmetrical design, the head containing only one center opening, of relatively small diameter, to receive the combined fuel valve and

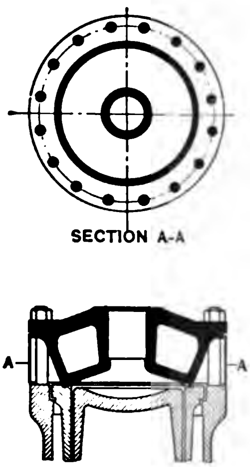


FIG. 90.—Busch-Sulzer two-cycle cylinder head.

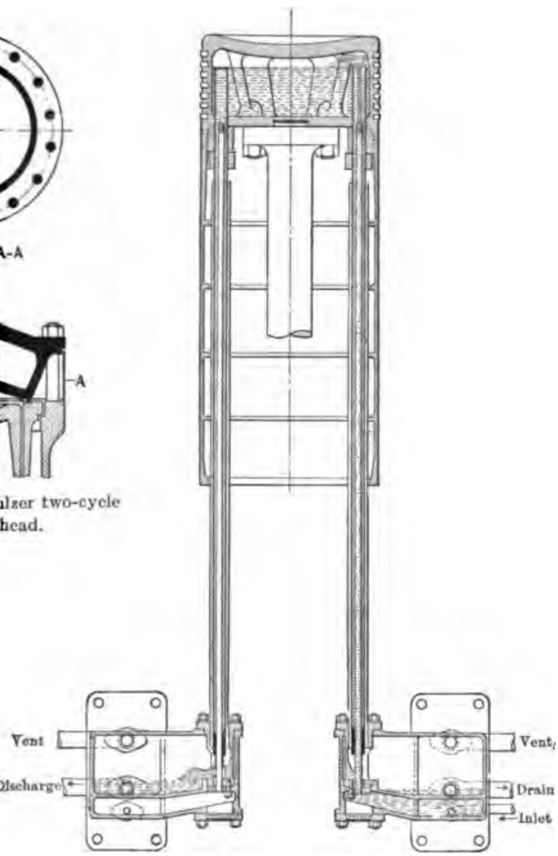


FIG. 91.—Busch-Sulzer piston cooling arrangement.

starting-valve cage; this insures freedom from casting and heat stresses and offers the greatest resistance to all working stresses. The heads do not contain any scavenging or exhaust valves. Ample circulating water space is provided, and the ring of relatively cool metal surrounding the hot center portion—common to some other designs—has been eliminated. The under side of the head is concave, forming in conjunction with the concave face of the piston a symmetrical combustion space of ideal shape. Scavenging air enters and the exhaust gases are discharged through ports in the cylinder wall, which ports are opened and closed to the cylinder by the piston which uncovers the ports on the down stroke, and covers them on the up stroke, near the lower end of its stroke.

On the scavenging side of the cylinder there are two tiers of ports. The upper tier is controlled by a timed rotary scavenging valve driven from the vertical shaft of the engine; the lower tier has a free opening into the scavenging air receiver. This patented arrangement insures excellent scavenging and the complete charging of the cylinder with pure air, while the scavenging valve is out of range of the hot gases. The marine engines are provided with double sets of starting and fuel cams and the necessary levers and gear to permit the direction of rotation of their crankshafts being promptly reversed. The gear is air-operated, and interlocking devices are provided to safeguard against starting or reversing except when in proper position. Governors are provided on the marine engines to prevent racing of the engine by cutting off the supply of fuel to the cylinder when the speed exceeds a predetermined limit. The supply of fuel is automatically re-established as soon as the speed of the engine falls to normal. In the stationary engines a suitable centrifugal spring-loaded governor regulates the speed by controlling the amount of fuel delivered to the cylinders and also the pressure of the injection air. With this type the multiple-fuel plunger pump, having one plunger for each cylinder, is operated from the vertical shaft. The amount of fuel delivered to each cylinder is determined by varying the seating point of the suction valve, either automatically by the governor or by hand from the control levers in the case of the marine engine. The piston proper is short, being merely long enough to accommodate the piston rings, as all guiding is performed by the crossheads. It is provided with a water jacket immediately under its upper face and is water-cooled by an arrangement of telescopic tubes in which all stuffing boxes or swing joints are eliminated, while oil and water leakage is prevented. See Fig. 91.

Immediately below the piston is fitted a skirt, the sole function of which is to cover the scavenging and exhaust ports in the cylinder wall. The crossheads are of the double-center guide type. The lower end of the piston rod is forked. The connecting rods are forged with marine type crosshead and crank ends. The crankshaft is in three sections, each being made from a single open-hearth heat-treated forging. The two main sections are interchangeable with one another; the third section carries the cranks for driving the scavenging pumps and air compressor and is provided with an integral flange to bolt to the main section. The shaft is bored to permit examination of the material and to afford passage for the lubricating oil. The scavenging pumps, where directly driven, for providing low-pressure scavenging and charging air for the working cylinders, are mounted vertically on the crankcase at the opposite end from the flywheel, next to the forward working cylinder, and in line with same. They are directly driven from the crank on the extension to the main crankshaft, and are provided with cross head and guide similar to those of the main cylinders. The suction and discharge valves are of simple, automatic "shutter" type, mounted in cages. The compressor for providing compressed air for fuel injection and starting is mounted vertically on the crankcase at the forward end of the engine in line with main cylinders. The compressor is three-stage, water-jacketed, and provided with adequate intercoolers and aftercoolers, to maintain the air at a low temperature. The general lubrication is a pressure system providing all main bearings, crank pin and crosshead pin bearings, crossheads, vertical shaft thrust bearings and lower helical gears, with a continuous supply of cool clean oil, under pressure.

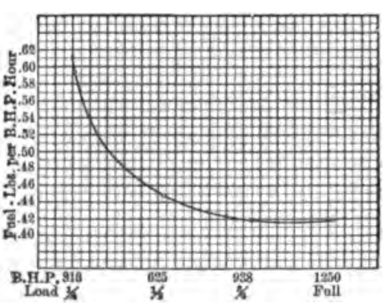


FIG. 92.—Busch-Sulzer two-cycle fuel consumption curve.

The fuel consumption at various loads of the Sulzer two-cycle type is shown at Fig. 92.

The Snow horizontal four-cycle Diesel engine is shown in section at Fig. 93. It is built in sizes up to 23-inch diameter cylinder and 36-inch stroke developing 600 B.H.P. in three cylinders. It is equipped with crosshead and short piston instead of a trunk

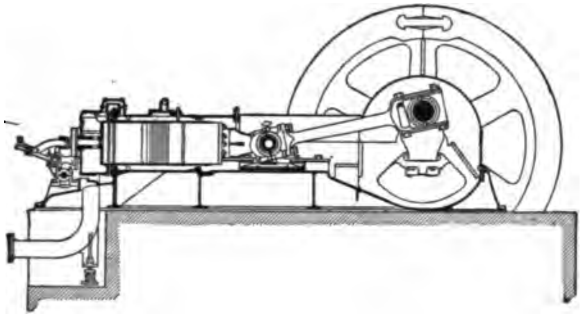


FIG. 93.—Snow Diesel section.

piston (the advantages of the crosshead have been referred to previously). The spray valve is of the open nozzle or Lietzenmeyer type, where the fuel is deposited in a pocket formed in the sprayer and is driven into the combustion space by the spraying air at high pressure. The fuel does not pass the spray valve seat and thus it is preserved. This type is illustrated at Fig. 64. The three-stage air compressor attached to

FIG. 94.—Indicator diagram (Snow).

this engine is illustrated at Fig. 58. The regulation of the speed of the engine is accomplished by varying the length of the suction stroke of the fuel supply pump plunger by means of a wedge which is under the control of the governor, and as the fuel has only to be lifted to the spray valve without opposing the injection air pressure the resistance to the governor is reduced to a minimum. An indicator diagram and a card taken under similar conditions but with the indicator drum with 90° lead is shown in Fig. 94, and the fuel consumption curve is shown in Fig. 95.

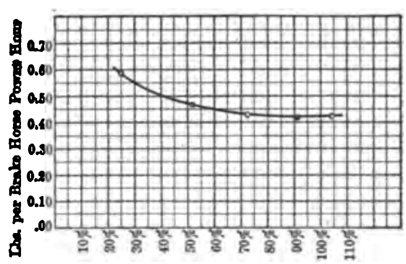


FIG. 95.—Fuel consumption curve (Snow).

The De La Vergne Diesel horizontal built in sizes of 180, in single-cylinder units, to 1080 H.P. in six cylinders, is shown in section at Fig. 96. The trunk piston constructed in two parts is made of such length as to allow sufficient surface in contact with the water-cooled surface of the cylinder liner, so that internal cooling is unnecessary. The diameter of the cylinder is 21 inches and 34½-inch stroke; 164 R.P.M.

With the multi-cylinder units the frames are interlocked and bolted together so as to insure perfect alignment of all crankshaft bearings.

The air compressor furnishing high-pressure air for injection purposes is itself self-contained and is operated through a flexible coupling from the engine crankshaft.

The McIntosh & Seymour four-cycle vertical Diesel engine is shown in section at Fig. 97, illustrating the design and construction of the cylinder, air and exhaust valves and cylinder head and three-stage air compressor actuated from the main crankshaft. These engines are built for stationary purposes from 100 B.H.P. in twin-cylinder units to 2300 B.H.P. in eight-cylinder units. Engines developing over 1000 B.H.P. are of the crosshead type with water-cooled pistons and built-up crankshafts. The marine engines are built in sizes from 390 I.H.P. to 3000 I.H.P. with six and eight cylinders. The arrangement of the piston is similar to that of the stationary type. Reversing of direction of rotation is by the usual method of longitudinal movement of the cam shaft, on which are keyed two sets of cams for ahead and astern, controlled by an

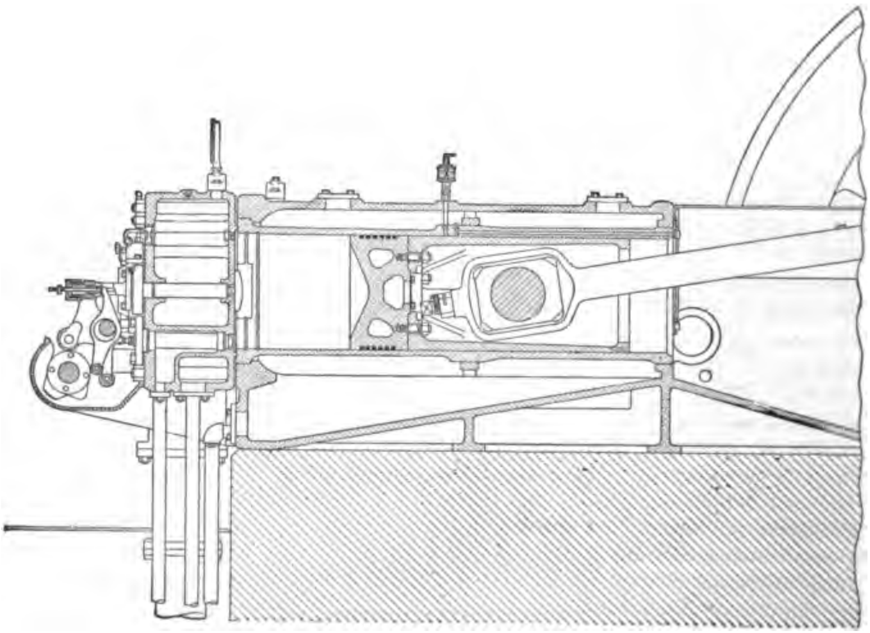


FIG. 96.—De La Vergne Diesel sectional view.

interlocking device insuring correct sequence of the various operations. An air-starting valve is provided for each cylinder. The valve motion consisting of rocking levers is operated on stationary engines from the overhead cam shaft actuated through gears and vertical shaft from the crankshaft. In the stationary type the speed is controlled by lengthening or shortening the stroke of the fuel-supply pump plungers, one for each cylinder. The action of the governor alters the relative position of the two eccentrics, one of which floats on the other which actuates the pumps. The fuel-inlet spraying valve is shown in Fig. 63. The makers state that these engines are operating successfully on 14°–18° Bé. gravity fuel, having 3 to 4 per cent sulphur content. Table 23 shows a test made on the earlier engines and in Table 10 are given the results of a test recently made. In Fig. 76 are shown details of an installation of two 1000 B.H.P. McIntosh & Seymour Diesel engines direct connected to generators.

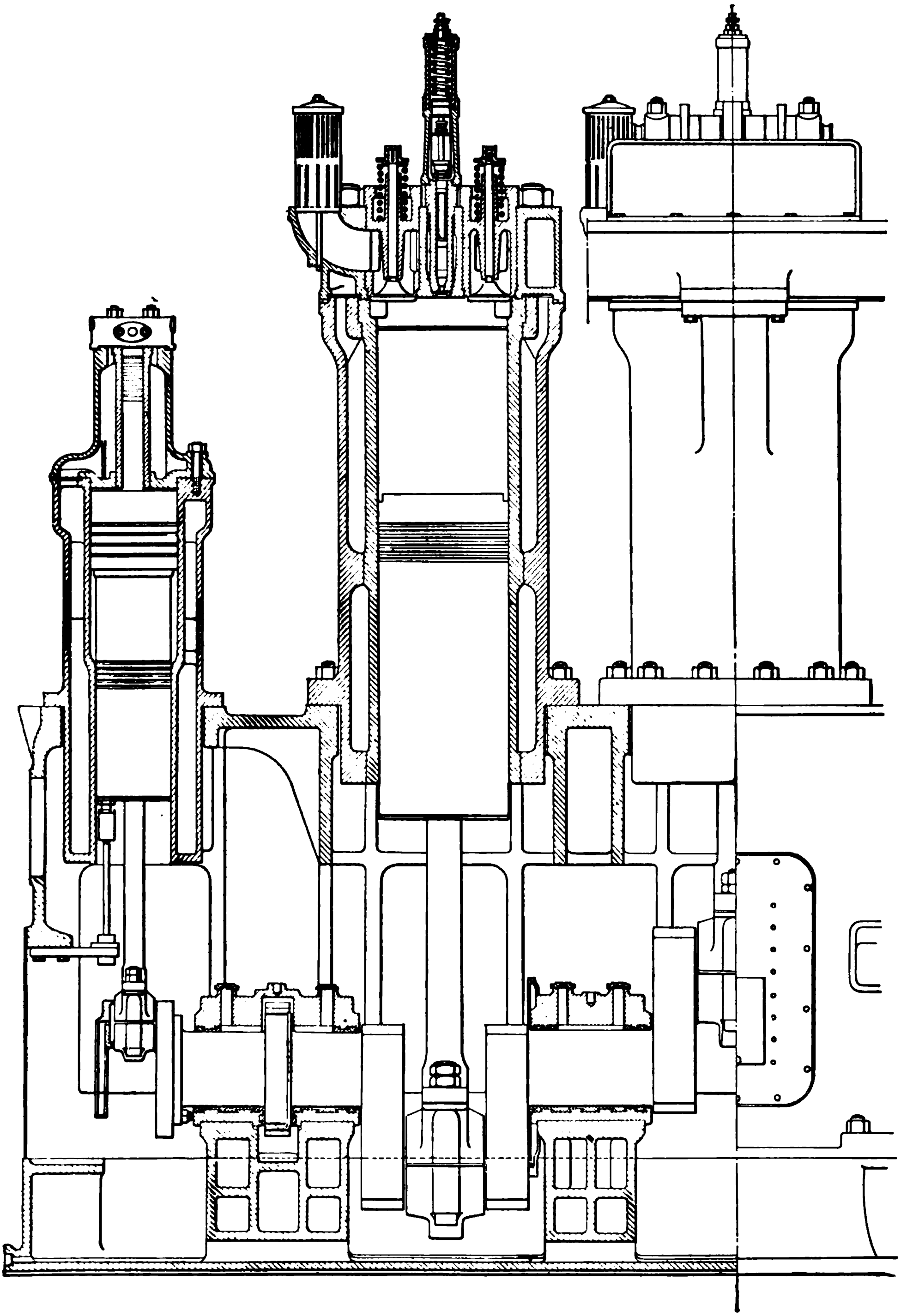


FIG. 97.—McIntosh & Seymour sectional view.

TABLE 10

Test of 500 H.P. McIntosh & Seymour Stationary Diesel Engine

Percentage of rated load	25.6	51.0	75.8	99.6	114.8
Revolutions per minute	168	167	166	163	168
Brake horse-power	128.2	255	379	498	574
Time of test in hours	½	½	½	1	1
Fuel consumption per B.H.P.-hour, pounds	.584	.432	.396	.393	.388
Injection pressure, pounds	750	775	800	800	900
Exhaust gas appearance	Clear	Clear	Clear	Clear	Clear
Inlet temperature of cooling water, degrees F	69	69	69	69	69
Outlet temperature of cooling water, degrees F	150	150	158	158	158
Temperature in testing-room, degrees F	73	73	72	78	79

MARINE DIESEL ENGINES

The success of the marine Diesel engine is evinced by the many hundreds of ships propelled by this method in continuous operation on every ocean and by the numberless manufacturers who are building them in all countries of the world.

Some of the advantages of Diesel engine ship propulsion in comparison with that of steam may be summarized as follows: (*a*) the space occupied is less than that required for the steam engine and boiler with consequent greater space available for cargo; (*b*) the number of attendants necessary is reduced, as stokers and coal trimmers are not required; (*c*) there is greater economy of fuel (the fuel consumption of a Diesel engine is less than 0.45 pound, and 0.38 pound has been recorded per B.H.P. per hour); (*d*) the liquid fuel is easier to store than coal; (*e*) a ship so equipped can travel a greater distance as less fuel is consumed; (*f*) smoke and large funnels are eliminated; (*g*) it is possible to start quickly and develop full power at a moment's notice; (*h*) standby losses are eliminated or reduced (fuel consumption ceases as the engines are stopped); (*i*) the store of fuel can be replenished in less time and if necessary, fuel can be transferred to the ship at sea.

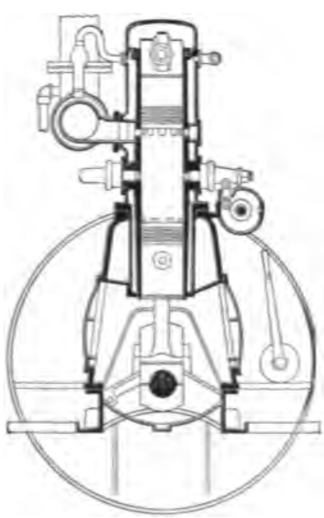


FIG. 98.—Junkers, sectional view.

Among the disadvantages of the Diesel marine engine the following may be named: (*a*) Skilled attention. Diesel engines require higher-grade and specialized engineers who may be unavailable or difficult to replace in cases of emergency in foreign ports; (*b*) Unreliability: Diesel engines built in previous years were wanting in reliability for continuous operation, but modern Diesel engines have proved themselves as reliable as steam engines.

The Junkers design of the two-cycle opposed-piston type Diesel oil engine is shown in Fig. 98. Each cylinder has two pistons which move simultaneously in opposite direc-

tions. The upper piston has a crosshead attached to its upper end working in guides with long connecting rods attached to the two outboard cranks placed at 180° from the center crank which actuates the lower piston. The fuel is injected into the combustion space formed between the opposing pistons when they come closest to each other. The exhaust ports, visible in Fig. 98, are first uncovered by the movement of the lower

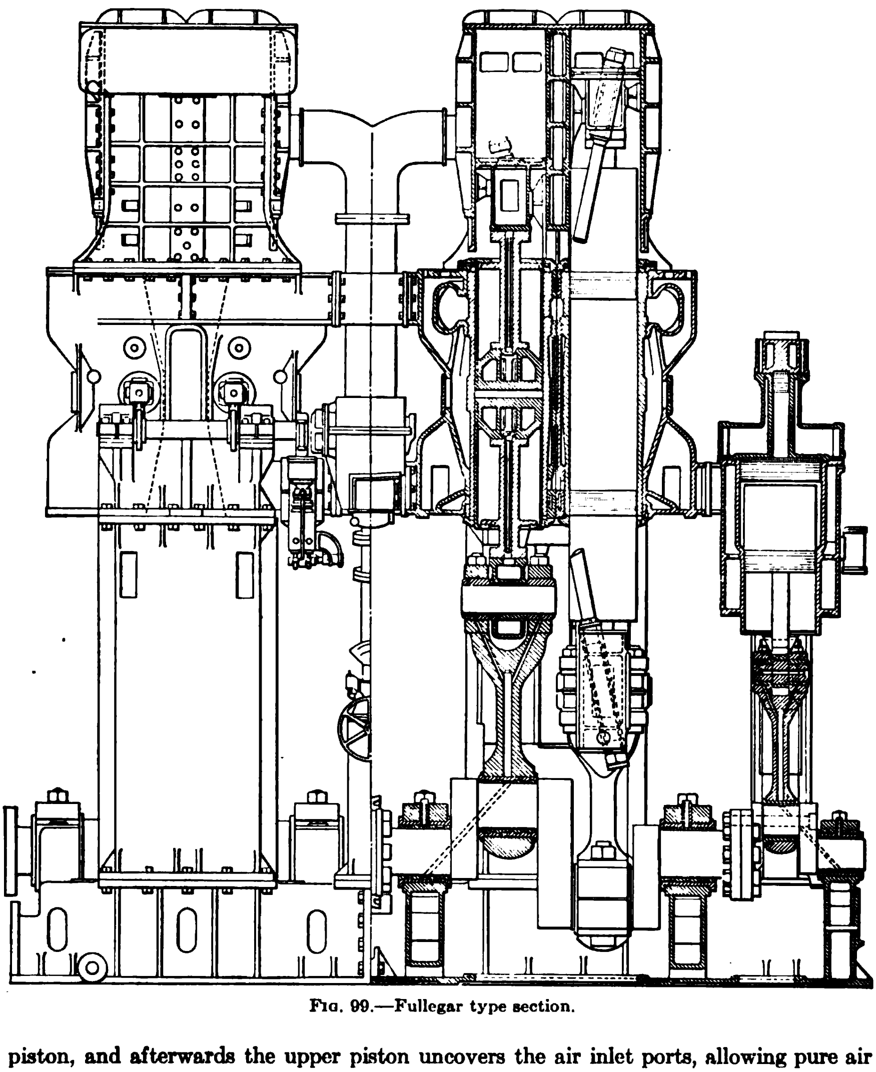


FIG. 99.—Fullegar type section.

piston, and afterwards the upper piston uncovers the air inlet ports, allowing pure air at a slight pressure to enter the combustion space and thoroughly scavenge it of products of combustion. Absence of cylinder head, elimination of strains transmitted through the cylinder, complete balance of reciprocating parts, ideal combustion space and decreased loss of heat to the cylinder water jackets are the advantages claimed for this design.

[1] Fig. 99 is reproduced from Motorship, April, 1920, where a detailed description of this type is given.

The Cammellaird-Fullegar opposed-piston two-cycle Diesel marine engine, shown in Fig. 99, operates on the same principle as the Junkers or Ochelhaüser engine above referred to, but in this type the upper piston in the one cylinder is connected by diagonal tie-rod to the lower piston in the other cylinder, as illustrated. The side thrust of these diagonal rods is taken by the upper and lower crossheads, the one placed above also forming the piston in the scavenging air pump. The great advantage of this design is

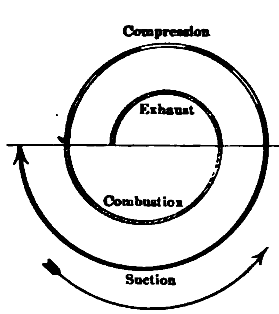


FIG. 100.—Ahead diagram valve periods four cycle.

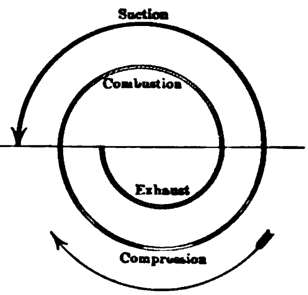


FIG. 101.—Astern diagram valve periods four cycle.

the saving in weight and space as compared with other types of Diesel engines. For instance, a 500 H.P. engine is 15 feet 6 inches in length over all, with height 40 feet 9 inches above the shaft centers operating at 120 R.P.M.; its total weight is approximately 45 long tons or about 190 pounds per B.H.P. The claim is made for this design that 2.22 times the power can be placed in the same space as is occupied by a two-cycle Diesel engine.

Reversing.—The feature of greatest importance found in the marine Diesel engine

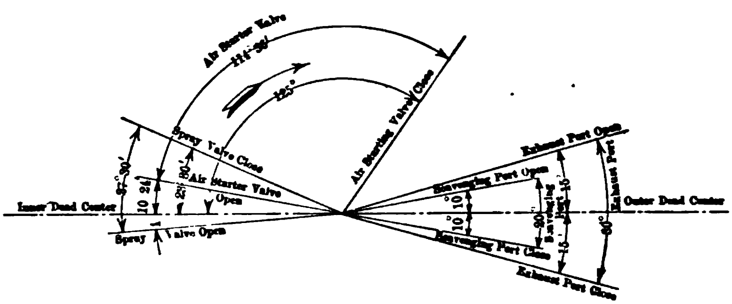


FIG. 102.—Valve settings ahead two cycle.

unnecessary with the stationary type, is that of direct reversing of the direction of rotation of the crankshaft, which has to be performed in a few seconds of time. With the four-cycle type the periods of air inlet, exhaust, combustion, etc., shown in diagram, Fig. 100, when the engine is going "ahead," have to be changed to those periods shown in Fig. 101 when going "astern." As the profiles of the cams in the proper positions for each direction cannot be superimposed this change cannot be effected by simply rotating the cam shaft through an angle relatively similar to the crankshaft and so the

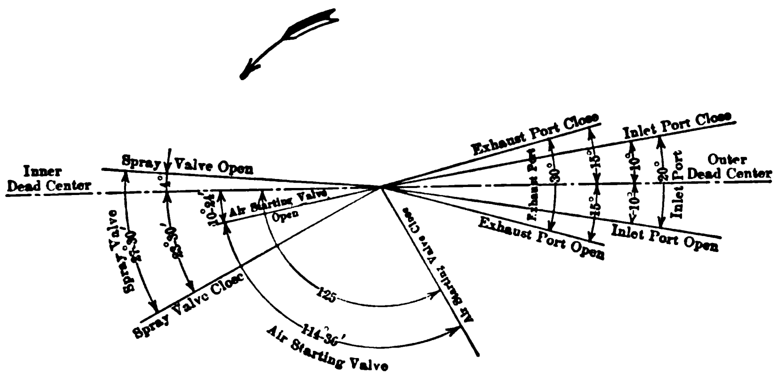


FIG. 103.—Valve settings astern two cycle.

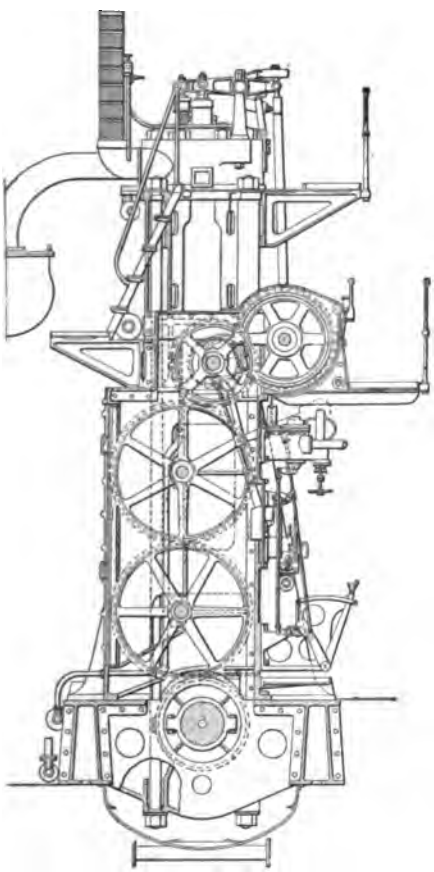


FIG. 104.—Burmeister & Wain sectional view.

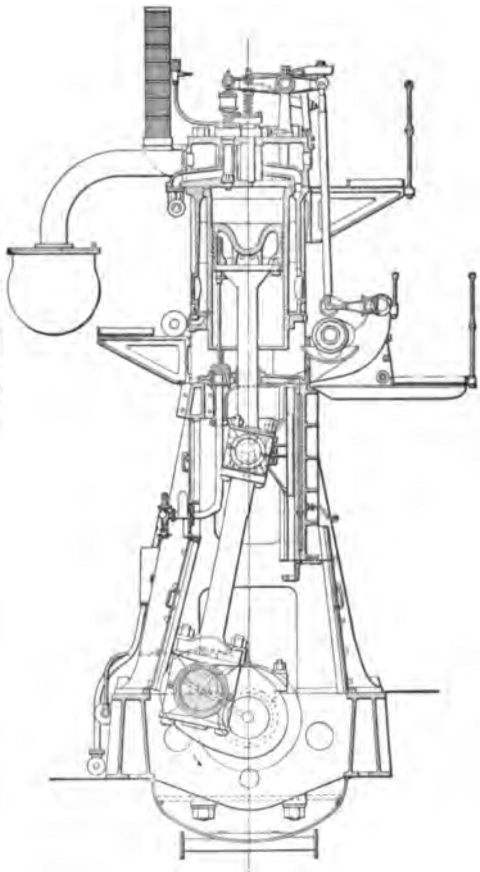


FIG. 105.—Burmeister & Wain sectional view.

most accepted and simple method is to provide two sets of cams, one for "ahead" and the other for "astern." These cams are each keyed to the cam-shaft, which is moved longitudinally so that either set of cams is brought in contact with its set of rollers as reversal of direction is to be effected. Compressed air furnished by an auxiliary unit is employed to start the engine and for maneuvering, as described in detail with some of the different types referred to hereafter. With the two-cycle type the process of reversal is simpler than with the four-cycle engine; the exhaust which issues through the ports in the cylinder wall does not require reversing, nor does the scavenging period. The fuel-injection period, as also the period of opening and closing of the scavenging valves if placed in the cylinder head, do require reversing. The diagrams of valve settings, shown in Fig. 102 and Fig. 103, indicate the different valve settings for two-cycle type "ahead" and "astern."

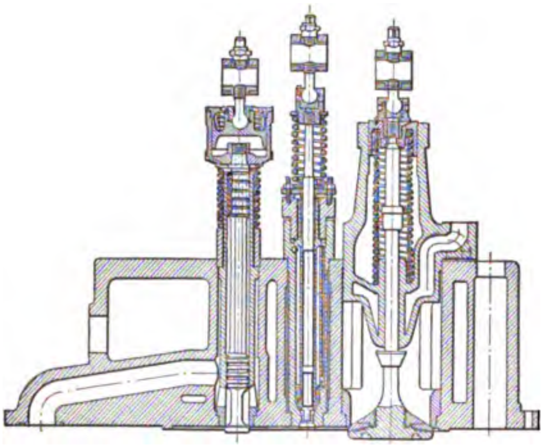


FIG. 106.—Burmeister & Wain cylinder head.

The Burmeister & Wain four-cycle single-acting Diesel marine engine is shown in section at Fig. 104. It was built first in Copenhagen and now also in England and in the United States by Wm. Cramp & Sons, Philadelphia. It is installed in numerous motor ships. The largest size thus far built is 3200 I.H.P., having cylinders $29\frac{1}{8}$ inches in diameter, $45\frac{1}{4}$-inch stroke, operating at 120 R.P.M. and developing, with 88 M.E.P., approximately 2400 B.H.P. in eight cylinders. The substantial construction of this design is seen in Fig. 104 and Fig. 105. Three cylinder casings are cast in one piece each with separate liners. The strain due to the impulse in the cylinders is absorbed by the through-bolts passing from the cylinder top to the under side of the main bearing. The cooling water circulating in the piston is furnished through telescopic tubing. The cylin-

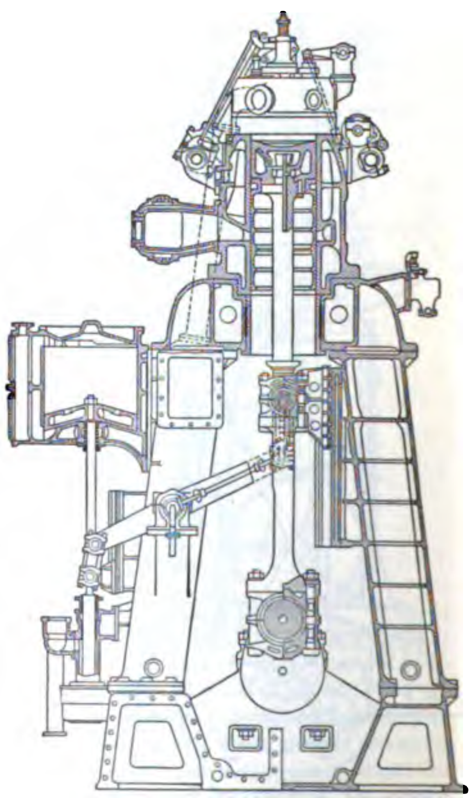


FIG. 107.—M. A. N. vertical two cycle marine.

der head is shown in Fig. 106 and contains the spray valve opening downward, the air inlet, the cast-iron exhaust, and starting valves. The exhaust-valve housing is thoroughly water-cooled. The process of reversing is effected by an auxiliary motor. The two sets of cams, one for " ahead " and one for " astern," first have their rollers lifted by means of the layshaft; then the cam shaft is moved lengthwise, as desired, to come in contact with the cams as required. An interlocking device prevents the regulator and reversing lever from operating simultaneously. No fuel or high-pressure air can enter the cylinder while the starting air is allowed to enter. Each cylinder is supplied by a separate fuel pump. Force-feed lubrication is furnished to all bearings, crosshead and piston.

The *M. A. N.* vertical two-cycle marine type Diesel engine of 1350 B.H.P. having four cylinders $25\frac{5}{8}$ inches in diameter and $36\frac{3}{16}$ inch stroke, having 120 R.P.M. is shown in Fig. 107. The method of reversing peculiar to this design is to allow sufficient "play" in the clutch on the intermediate cam shaft so that the cams have a backward movement of 30°. The different positions of the valve openings on this engine for " ahead " and " astern " are shown in Fig. 108.

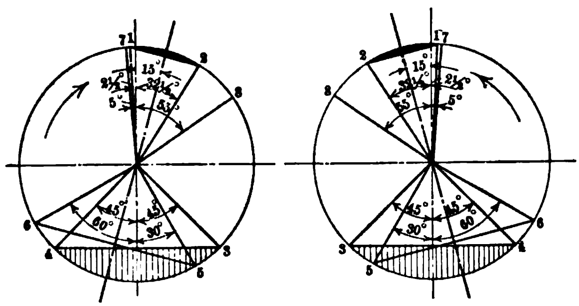


FIG. 108.—(1) Fuel inlet valve opens. (2) Fuel inlet valve closes. (3) Exhaust port opens. (4) Exhaust port closes. (5) Scavenging air valve opens. (6) Scavenging air valve closes. (7) Starting air valve opens. (8) Starting air valve closes.

The Vickers marine Diesel engine with solid fuel injection, as installed in the motorship " Narragansett," is shown in Fig. 109. The patented method of fuel injection has already been described with other sprayers. The main frame construction of this design consists of hollow cast-iron columns straddling the main bearings and bolted to the bed plate. The cylinders are bolted to the tops of these columns. The cylinder casings are bolted in two groups of three each, bore $24\frac{1}{2}$ inches diameter and 39 inches stroke, and the engine develops in six cylinders 1250 B.H.P. at 118 R.P.M. The forged steel crankshaft is divided into three-throw parts coupled together with crank pins set at 120° apart. In order to obviate trouble from torsional vibration the sequence of impulses in the cylinders is 1, 5, 3, 6, 2, 4. The columns support the single slipper crosshead guides, and while they impart rigidity to the engine, the stresses from each impulse are not carried through them but are absorbed through the sixteen steel tie-rods that pass through the columns. The cam shaft placed horizontally at the top of cylinders is actuated from the crankshaft through spur and bevel gearing, which mechanism is placed in the center of the engine. Two sets of cams for " ahead " and "astern" are mounted on the cam shaft, and above the cam shaft is placed the shaft which carries the fulcrum levers. These are mounted eccentrically so that by partial rotation of the shaft the rollers in contact with the air inlet and exhaust cams can be raised to clear them.

The process of reversing the direction of rotation of the engine is effected by a servo-motor which is furnished with an oil buffer cylinder and is operated by compressed air from the air receivers. The piston rod of this servo-motor is equipped with a toothed rack which engages with a spur wheel which turns a crank through one complete revolution when reversal takes place. This crank imparts to a fulcrum shaft a motion to and

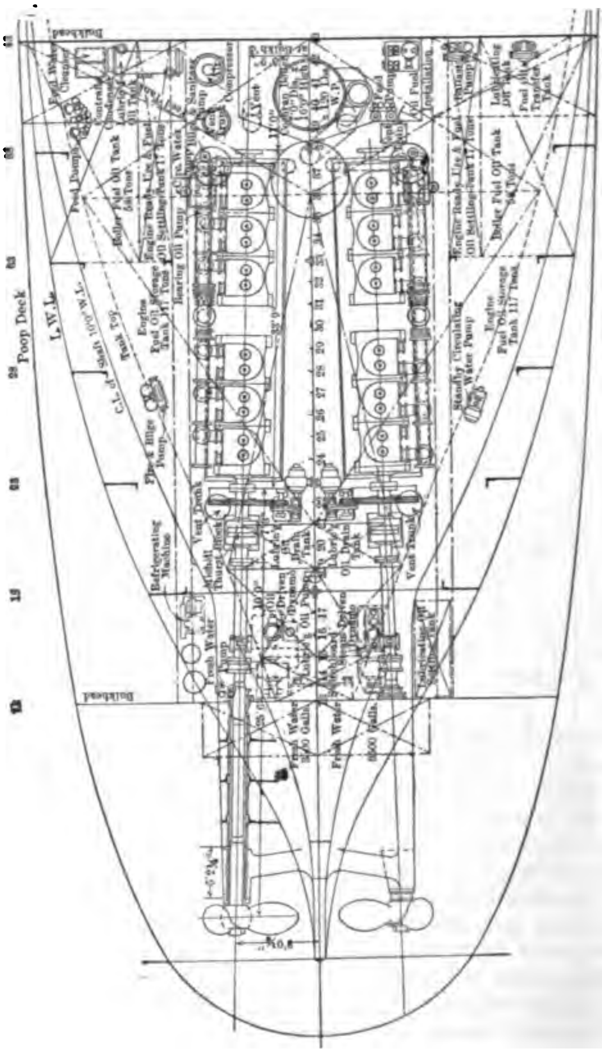


Fig. 109.—Vickers engine, "Narragansett."

fro during its travel. The inlet and exhaust valve levers are mounted eccentrically on this fulcrum shaft. A roller rotating on a pin attached to the back of this rack engages in a suitably shaped slot formed in one end of the lever (arranged for sliding the cams) fulcrumed at its center, the other end engages that part carrying the cams. The action of this mechanism is as follows: During the first part of the stroke the air

piston of the servo-motor through the agency of the rack, spur wheel, crank, connecting rod, etc., turns the eccentric fulcra on which the inlet and exhaust valve levers are mounted and thereby raises the rollers attached to these levers from contact with the cams. When they are free (the air piston still continuing its stroke) the roller on the back of the rack leaves the straight part and enters the curve in the slot formed in one end of the lever, which action causes the cams to move longitudinally until the "astern" cams come under the rollers and are in the position previously occupied by the "ahead" cams. Still further movement of the air piston causes the roller on the rack to enter the straight part of the slot, and then no further longitudinal movement of the cams is possible as the cam shaft becomes locked in position. The further travel of the air piston causes such a movement of the eccentric fulcra as results in the rollers of the inlet and exhaust valve levers engaging the cams again. A pneumatic stop prevents the gear from "creeping," should the air pressure fail. The starting wheel remains locked at the position "stop" unless the lever (for ahead–astern) is placed in the correct position for "ahead" or "astern" and until the reversing mechanism has completed the order thereby indicated. The exhaust gases from all six cylinders of each engine are conducted to a common manifold which is properly insulated. The pistons are cooled internally by sea water passing to and fro through telescopic connections. The exhaust valve is also water cooled. Lubrication to all moving parts is effected by force-feed pumps operated from the crossheads. An indicator diagram from this engine is reproduced in Fig. 110. The fuel consumption was 0.385 pound per B.H.P. hour during a 2½-hour maximum speed trial using fuel 27° Bé. (0.894 specific gravity).

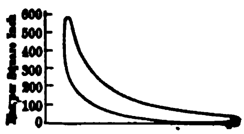


FIG. 110.—Vickers indicator diagram.

The motorship "Narragansett" has the following dimensions, etc.

TABLE 11

Displacement	14,000 tons
Dead weight capacity (maximum)	10,500 tons
Dead weight capacity (normal)	10,050 tons
Cargo capacity on 26 feet draft	9,450 tons
Fuel capacity	750 tons
Cruising radius	68 days
Cruising radius	18,000 nautical miles
Capacity of main tanks	434,000 cubic feet
Capacity of Summer tanks	52,000 cubic feet
Total cargo capacity	486,000 cubic feet
Length	425 feet
Breadth (molded)	56 feet 8 inches
Depth (molded)	33 feet
Draft (molded)	26 feet
Contra t speed	10.50 knots
Trial speed (26 feet 2 inches draft)	11.24 knots
B.H.P	2,500
Cylinders and R.P.M	24½×39 inches, 118 R.P.M.

Auxiliary machinery—Steam—Auxiliary oil engine Vickers, Petters. *Messrs. Vickers, Limited,* give the following information regarding trips made by the "Narragansett."

TABLE 12

From................. To...................	New Orleans Liverpool	Barrow New York	New York London	Liverpool New York	New York Liverpool
Date from............	7-7-20	25- 9-20	16-10-20	16-11-20	4-12-20
To...................	22-7-20	9-10-20	30-10-20	30-11-20	17-12-20
Distance, miles........	4528	3013	3204	2985	3028
Running time, hours...	402	325½	313	317	289
Av. speed, actual knots	11.1	9.25	10.2	9.41	10.48
Mean rev. of engine...	118	111	117.3	114.4	117.9
Engine fuel used per day, tons...........	9.61	9.36	10.51	9.23	10.76
Boiler fuel used per day, tons...............	2.13	2.16	1.71	2.95	2.03
Total fuel consumption per day, tons.......	11.74	11.52	12.22	12.18	12.79

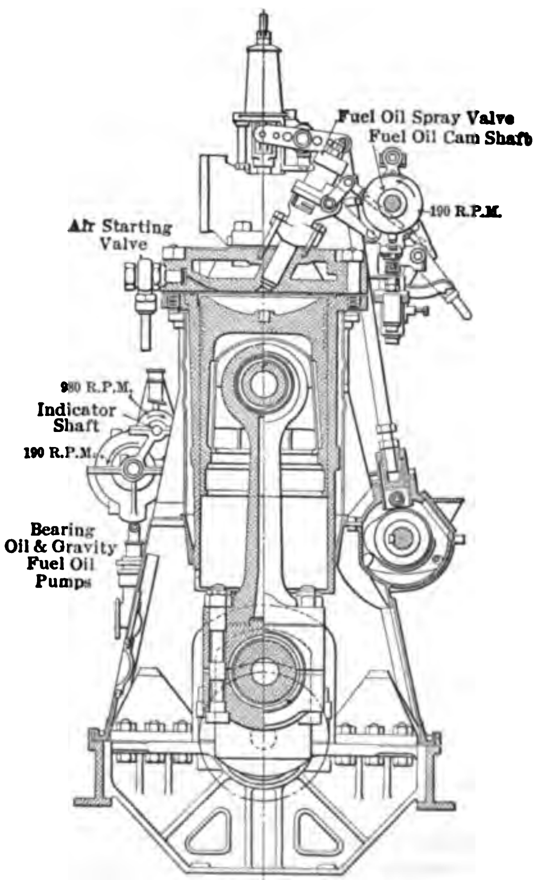


FIG. 111.—Vickers submarine-type sectional views.

The owners state that with a similar oil-fired steam vessel the average speed being 10.25 knots, the daily consumption of oil is approximately 35 tons, while the daily consumption of fuel in a coal-fired steam tanker very slightly larger than the "Narragansett" is 55 tons at 9.8 knots speed.

The **Vickers submarine** twelve-cylinder high-speed Diesel engine is shown in section at Figs. 111 and 112. The construction of the main frames and the method by which the main bearings are carried in separate steel castings recessed into longitudinal beams is illustrated. The columns consist of boiler plate approximately 11/16 inch thick with a forged steel head placed on the top into which these plates are rabbeted, while the forgings are riveted at the bottom. On the column head is placed a distance piece which takes the weight of the liner and to which the cylinder cover is bolted by six 1¼-inch bolts. This construction is of minimum weight, very accessible for inspection or repairs and permits close determination of stresses. The cylinder cover is a

simple steel casting with air-inlet and exhaust-valve housings inserted which are thoroughly water-cooled. These valves are of nickel steel, the exhaust valve being also water-cooled internally. The cylinder liner is of cast iron surrounded by a corrugated steel-jacket forming the water-circulating space. The cast iron trunk piston has concave-head and is fitted with six piston rings and also a wiper ring at its lower end. The piston gudgeon pin bearing consists of a non-adjustable bronze bushing babbitt-lined and lubricated through the hollow connecting rod. The crankshaft is in four sections, three cranks forming one section composed of nickel chrome 7½ inches in diameter with hollow

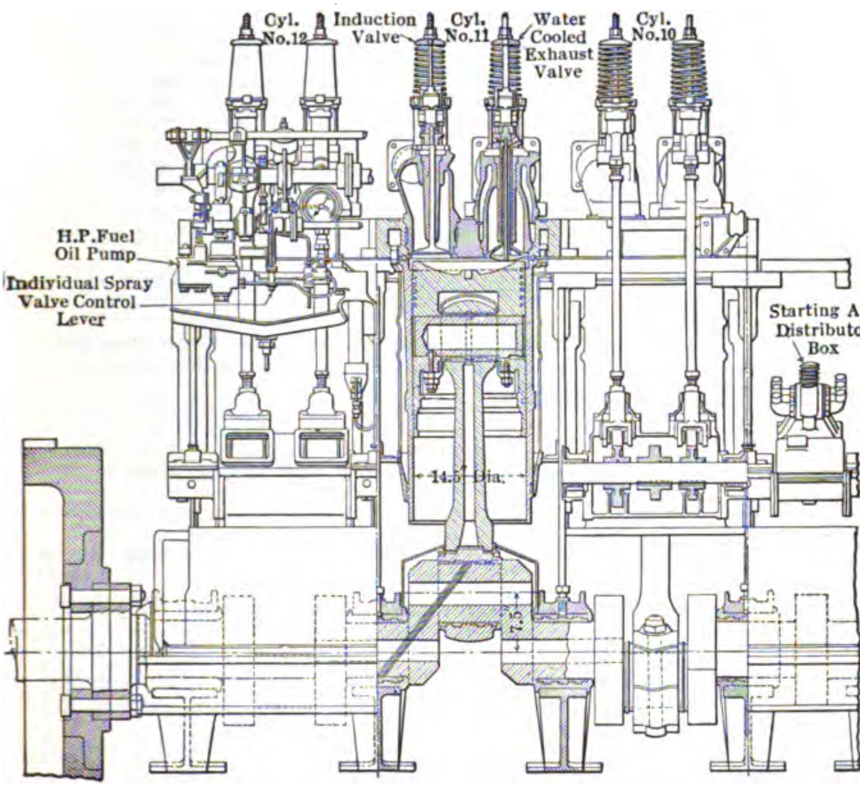


FIG. 112.—Vickers submarine type sectional views.

journals and crank pins. The exhaust manifold is water-jacketed and is connected to each six cylinders. The order of firing is 1, 7, 3, 9, 2, 8, 6, 12, 4, 10, 5, 11, and is so arranged to eliminate or minimize danger from torsional vibration. The method of fuel injection is described elsewhere. In this type injection commences about 16° before the inner dead center.

This engine develops 1200 to 1400 B.H.P. at 380 R.P.M. and 400 R.P.M. respectively. In Table 13 are shown the results obtained during a six-hour test. (Full detailed description of this design will be found in " Engineering " July 4th, 1919.)

TABLE 13

Six Hours' Official Test on Vickers Submarine Engine 1200 *B.H.P., September* 5, 1918

Time	R.P.M.	B.H.P.	Fuel used		Fuel pressure	Controls at		Circulating water	Lubricating Oil			Atmospheric temperature
			Lb. per Hour	Lb. per B.H.P.-Hour		Fuel pump	Spray valves	Pressure	Pressure	Temp. F. In	Temp. F. Out	
					Lb. per sq. in.			Lb. per sq. in.	Lb. per sq. in.	Deg.	Deg.	Deg.
1st hour	379.8	1209.9	461	0.381	4500	9	18.5	10	12	68	87	60
2d hour	382.5	1218.5	461	0.379	4500	9	18.5	10	12	71	101	62
3rd hour	381.0	1213.9	461	0.380	4500	9	18.5	8	10	72	106	64
4th hour	381.8	1216.3	457	0.376	4500	9	18.5	8	8	87	109	62
5th hour	381.4	1215.0	479	0.394	4500	9	18.5	10	12	98	116	63
6th hour	381.7	1216.0	461	0.380	4500	9	18.5	10	12	104	114	63
Average	381.3	1215.0	463	0.381	—	—	—	—	—	—	—	—

Indicated horse-power, 1520.

Inspecting Officer's Report: "The engine ran steadily and well, and no trouble of any sort was experienced throughout the trial. The crank pits remained clear of gases, and the exhaust was light and good. The trial is considered satisfactory."

Official Starting and Reversing Trial, April 26, 1919

From	To	Condition of engine	Volume of compressed air in use	Air pressure Before	Air pressure After	Air pressure Difference	Time to start	Revolutions to start
			Cu. ft.	Lb.	Lb.	Lb.	Sec.	
Stop	Ahead	Cold	36.4	550	525	25	5	8.0
Stop	Ahead	Cold	36.4	525	510	15	3	4.0
Stop	Ahead	Cold	36.4	510	495	15	3	4.0
Stop	Ahead	Cold	36.4	495	485	10	3	4.0
Stop	Astern	Cold	36.4	480	465	15	2	3.0
Stop	Astern	Cold	36.4	465	450	15	2	2.5
Stop	Astern	Cold	36.4	450	440	10	2	2.5
Stop	Astern	Cold	36.4	440	425	15	2	2.5
Astern	Ahead	Slightly warm	36.4	400	380	20	15	
Ahead	Astern		36.4	380	365	15	16	
Astern	Ahead		36.4	365	355	10	16	
Ahead	Astern		36.4	355	345	10	15	

NOTE.—Load condition is at full power.

The fuel system was primed by hand for the first start to approximately 400 pounds pressure. This was not necessary for the subsequent starts, as there was sufficient residual pressure in the system. For reversing no hand priming was carried out.

Of the time taken to reverse the engine, from 13 seconds to 14 seconds were absorbed in hand manipulation of shutting off and opening the controls and actuating the reversing wheel. Number of turns of reversing wheel from full ahead to full astern equals 23.

Loss in air pressure due to working of servo-motor. With air at 380 pounds per square inch in five receivers of 50 cubic feet capacity each the reversing gear was moved from ahead to astern and back 12 times. The air pressure dropped to 350 pounds per square inch; i.e., 24 movements of servo-motor caused a loss of 30 pounds per square inch in the starting air pressure.

Time taken to reverse.—The engine was reversed from full power ahead to full power astern in 6 seconds.

TABLE 14

Standard Table of Comparison of Steam and Oil-Engined Vessels

Compiled by Messrs. Vickers, Limited

	Diesel engine		Reciprocating steam engines	
Type of propelling machinery	Four-cycle single acting reversible, crosshead. Steam driven auxiliaries		Triple expansion engines, cylindrical boilers. Howden forced draught. Superheat 50° F.	
			Oil-fired boilers	
Total deadweight in tons	10,050		10,235	
Freight earning cargo in tons	9,357		8,555	
Average sea power, horse-power	2,500 (shaft)		2,800 (indicated)	
Radius of action in miles	10,500		10,500	
Fuel consumption per brake horse-power-hour, including auxiliaries, in pounds	.55 estimated		1.4	
Fuel consumption per day in tons	14.7		37.5	
Fuel consumption per voyage of 16 days in tons	235		600	
Comparative Costs of Working £1 = $4.86				
Provisions, total per month	£251.5.0	$1,221	£260.5.0	$1,264
Wages, total per month	£631.10.0	$3,068	£637.10.0	$3,098
Fuel, per 16 days sailing	£2,704 (£11.10 per ton)	$13,141 $56	£6,223 (£10.7.6 per ton)	$30,243 $52
Fuel, per month of 24 days sailing	£4,056	$19,710	£9,334	$45,163
Cost of running for one year of 288 days' sailing	£76,536	$371,962	£137,764	$669,533
Tons of freight earning cargo carried, assuming 9 round voyages per year, each of 32 days' total sailing out and home	168,426		153,990	
Cost per ton of cargo carried per 16 days sailing out and home	9/1d.		17/11d.	
Cost per ton mile	.027d		.053d.	

The above table has been prepared to show the comparison between oil- and steam-engined vessels, the size of vessel under comparison being one of the "Narragansett" dimensions. It will be understood that the values used in the preparation of this table are constantly varying, but an approximate idea can be obtained at any time by allowing for such fluctuations, the fuel costs on which the table is based being given. Actual results as quoted above show that considerably greater fuel saving is effected in actual practice.

The figures given on this sheet will, of course, vary with the particular size of vessel under consideration. In a typical case of a vessel of 2500 tons deadweight capacity

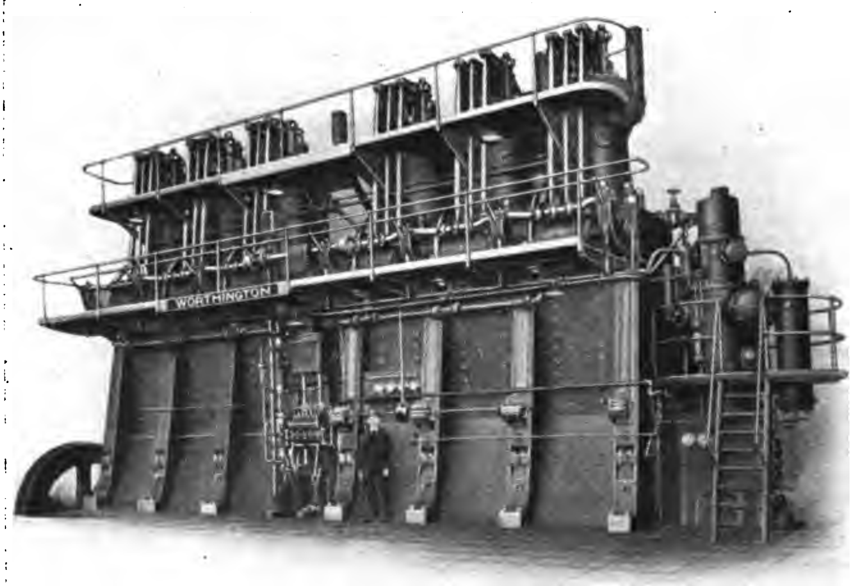


Fig. 113.—Worthington six-cylinder marine engine.

and 1500 shaft H.P. similar calculations show the total running costs for a voyage of 20 days, allowing for fuel, wages and provisions, etc. to be as follows:

£2,650 for the motor vessel
£4,780 for the same ship with oil-fired steam plant.

A comparison of the saving in cost of fuel alone for the voyage to and from New Orleans of the M. V. "Narragansett," as compared with a vessel of the same dimensions having oil-fired boilers, is given hereunder:

Table 15

M. V. "Narragansett"

Oil-fired steamship, 1289 tons of oil fuel at £10–7–6 per ton	£13,373
M. V. "Narragansett," 386 tons of oil fuel at £11–10–0 per ton	£4,439
Actual saving effected in oil fuel alone in one return voyage	£8,934

The consumptions taken in the above comparison are for main engines, auxiliaries, heating, steering, etc.

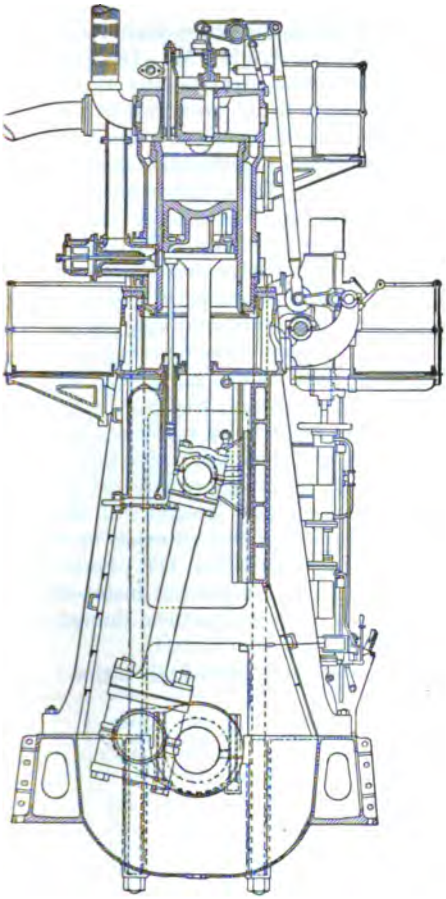


Fig. 114.—Worthington six-cylinder marine, sectional view.

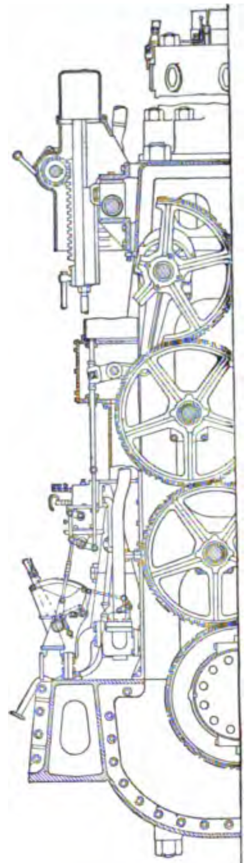


Fig. 116.—Worthington six-cylinder marine, interlocking device.

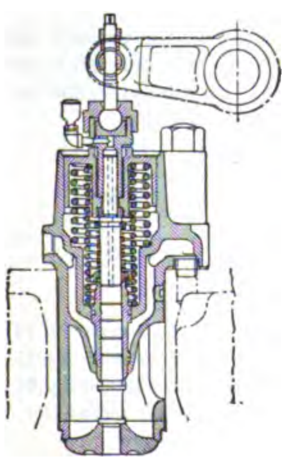


Fig. 115.—Worthington six-cylinder marine, exhaust valve and housing.

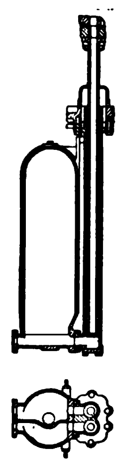


Fig. 117.—Worthington six-cylinder marine, telescopic piston, cooling piping.

The Worthington marine six-cylinder four-cycle single-acting Diesel engine is shown in Fig. 113. It develops 2400 I.H.P. (1750 shaft H.P.) at 120 R.P.M. The sectional view, Fig. 114, shows the details of construction, including crosshead and the 5-inch diameter through bolts which pass through the A frames to the lower side of the bed plate and which absorb the stresses due to the impulses in the cylinders. The A frames are provided with a removable section at their lower end so as to facilitate the removal of the crankshaft if necessary after raising the tension rod. The cylinders are each cast separately, with separate liners inserted in the usual manner. The cylinder head is provided with four valves. The air-inlet and exhaust valves (as shown in Fig. 115) have housings interchangeable with each other. The fuel-inlet valve and the automatic check-valve for air starting are so arranged as to allow ample circulation of cooling water. Reversing is accomplished by longitudinal movement of the cam shaft and two sets of cams, one for "ahead" and one for "astern" being provided. The reversing arrangement is actuated by a compressed-air reversing motor. The interlocking mechanism and cam shaft gear drive are illustrated in Fig. 116, and are so arranged that it is impossible to shift the reverse gear when either the starting air or fuel is being supplied. Neither can the engine be started when the reverse gear is off the correct position for going "ahead" or "astern." The crankshaft is of the built-up design constructed in two sections, each having three cranks, each crank pin being forged integral with its two webs. It is composed of open-hearth steel. The piston is cooled internally by water circulation introduced through a telescopic tube as illustrated in Fig. 117. Force feed lubrication to all principal moving parts is furnished by an independent motor-driven pump. Lubricant for the crosshead guides and pin is conducted to them through the hollow connecting rod.

The following are the principal dimensions and other particulars of this engine.:

TABLE 16

Indicated H.P.	2400
Shaft H.P.	1750
Mean indicated pressure	85.5 pounds
Mean effective pressure (brake)	64 pounds
Mechanical efficiency	75 per cent
Cylinder bore and stroke	29 inches by 46 inches
Number of cylinders	6
Compression pressure	500 pounds per square inch
Fuel-injection air pressure	900 pounds per square inch
Starting air pressure	375 pounds per square inch
Weight, complete	339 long tons
Weight per I.H.P.	327 pounds
Length with compressor	45 feet
Length with flywheel and thrust block	55 feet 6 inches
Height from crank center to top of valve motion	23 feet 10 inches
Crankshaft (weight)	$36\frac{1}{2}$ tons
Thickness of crank webs	$11\frac{5}{8}$ inches
Main bearings	$17\frac{1}{2}$ inches diameter by 24 inches long
Crank pins	18 inches diameter by 15 inches long
Crosshead pins (twin)	$10\frac{1}{2}$ inches diameter by $9\frac{1}{2}$ inches long
Piston rod	9 inches diameter
Thrust block	Kingsbury type

The following table shows the comparison of the space occupied by various plants. The space is given in square feet per working B.H.P.[1]

TABLE 17

Floor Space

	Rated working load B.H.P.				
	100	200	00	400	500
Diesel engine	1.35	0.95	0.87	0.725	0.68
S I. engine / Suction-gas engine / Town-gas engine	1.65	1.2	1.0	0.9	0.8
Locomobile	1.6	1.1	0.98	0.96	0.91
Producer plant (coal)	0.98	0.85	0.8	0.78	0.75
Producer plant (wood)	2.5	1.8	1.56	1.3	1.2

[1] Transactions of Inst. Mech. Eng., by Oswald Wans, 1917.

TABLE 18

Comparison of Efficiencies of Various Types of Power Plants[2].

Heat Units in Fuel Consumed per Brake Horse-power per Hour

Load per cent of rated H.P.	Simple non-condensing Corliss engines		Compound condensing Corliss engines		Triple expansion steam engines		Steam turbines		Diesel engines		
	Engine rating 100 I.H.P. Boiler pressure 100 pounds. Steam per I.H.P. hour, 28 pounds	Engine rating 400 I.H.P. Boiler pressure 150 pounds. Steam per I.H.P. hour, 24 pounds	Engine rating 200 I.H.P. Boiler pressure 125 pounds. Vacuum 25 inches. Steam per I.H.P. hour 15 pounds	Engine rating 800 I.H.P. Boiler pressure 180 pounds. Vacuum 27 inches. Steam per I.H.P. hour 13 pounds	Engine rating 400 I.H.P. Boiler pressure 150 pounds. Vacuum 27 inches. Steam per I.H.P. hour 12.5 pounds.	Engine rating 1000 I.H.P. Boiler pressure 200 pounds. Superheat 100° F. Vacuum 27.5 inches. Steam per I.H.P. hour 10.5 pounds	Rating 500 KW. Boiler pressure, 150 pounds. Vacuum 26 inches. Steam per KW. hour 21 pounds	Rating 5000 KW. Boiler pressure 200 pounds. Superheat 150° F. Vacuum 28 inches. Steam per KW. hour 14 pounds	Engine rating 165 B.H.P.	Engine rating 520 B.H.P.	Engine rating 2200 B.H.P.
100	52,500	41,500	25,500	21,000	20,000	17,500	21,000	15,000	9,000	8,400	8,000
75	60,000	47,500	29,000	23,500	22,500	20,000	23,500	17,500	9,500	8,900	8,500
50	79,000	59,500	36,500	29,000	28,000	24,500	27,000	20,500	10,800	9,800	9,000
25	138,000	99,000	58,000	45,000	43,000	36,000	36,000	28,000	15,400	13,000	12,000

For steam plants add allowance for standby, according to character of load.

To obtain equivalent pounds of coal divide B.t.u. by 12,500
To obtain equivalent pounds of fuel oil divide B.t.u. by 18,800
To obtain equivalent gallons of fuel oil divide B.t.u. by 143,000

[2] Compiled by Busch Sulzer Bros. Diesel Engine Co.

TABLE 19

De La Vergne Oil Engines, Various Types

Type	Rated B.H.P.	Cylinder diameter, inches	Stroke inches	R.P.M.	Load	Fuel pounds per B.H.P. hour	Compression pressure, pounds	Maximum pressure, pounds	Duration of test	Outlet, water temperature °F.	Date of test
"DH"	65	14	24	240	Full	0.485	195	465	1 hour	130	Nov. 1, '20
"DH"	65	14	24	240	10 per cent overload	0.502	195	465	1 hour	130	
"DH"	65	14	24	240	¾ load	0.485	195	465	1 hour	130	
"DH"	65	14	24	240	½ load	0.53	195	465	1 hour	130	
"FH"	140	20	34½	164	Full	0.48	275	475	1 hour	180	Nov.27,'19
"FH"	140	20	34½	164	10 per cent overload	0.483	275	445	1 hour	180	
"FH"	140	20	34½	164	¾ load	0.468	275	445	1 hour	180	
"FH"	140	20	34½	164	½ load	0.5	275	445	1 hour	180	
		(Twin)									
"SI"	200	17	27½	200	Full	0.420	320	540	1 hour	150	Oct. 5,'20
"SI"	200	17	27½	200	10 per cent overload	0.421	320	540	1 hour	150	
"SI"	200	17	27½	200	¾ load	0.410	320	540	1 hour	150	
"SI"	200	17	27½	200	½ load	0.458	320	540	1 hour	150	
		(3-cyl.)									
Diesel	540	21	34½	164	Full	0.40	440	550	1 hour	125	Oct. 5, '20
Diesel	540	21	34½	164	10 per cent overload	0.40	440	550	1 hour	125	
Diesel	540	21	34½	164	¾ load	0.43	440	550	1 hour	125	
Diesel	540	21	34½	164	½ load	0 479	440	550	1 hour	125	

The above engines operate on fuel oil or crude oil produced in the United States or Mexico, containing not less than 18,000 B.t.u. and not more than 1 per cent water.

The fuel oil used in some of the above tests was as follows:

Specific gravity	0.8794	Tar (Asphalt)	0.542 per cent
Saybolt viscosity at 100° F.	67	Moisture	1 per cent
Flash point Cleveland open	200° F.	Ash	.16
Fire point Cleveland open cup	230° F.	B.t.u.	18,677

TABLE 20

Operating Record of Type F. H. 130 H.P. De La Vergne Oil Engine, Direct Connected through Flexible Coupling and Friction Clutch to a Horizontal Geared Oil Pump for a Period of 8 Years, from 1912 to 1919, Inclusive

Year	Hours run	Fuel oil consumed (gallons)
1912	8,254	49,525
1913	8,040	41,826
1914	6,288	37,378
1915	6,608	36,360
1916	8,454	54,392
1917	8,333	57,130
1918	8,052	69,368
1919	8,011	60,641
Total	62,040	406,620 Avg. 6.55 per hour

Fractional hours omitted.

Number of hours, Jan. 1, 1912, to Dec. 31, 1919	70,128
Hours engine run	62,040
Hours engine idle	8,088
Hours idle account of repairs	3,802
Hours idle from various causes	4,286
Total cost of repairs, Jan. 1, 1912, to Dec. 31, 1919*	$3,685.79
Total cost of lubricating oils, Jan. 1, 1912, to Dec. 31, 1919	955.71

* Includes repairs during high cost period of war. The average cost of repairs for such engines in continuous yearly operation varies and may be approximated between 2.0% and 3.5% per year.

The operating force consists of six men, three engineers and three assistants, working in eight-hour shifts. The plant operates twenty-four hours a day and while one man is capable of handling the plant, the nature of the business is such as to demand two men for the margin of safety.

TABLE 21

Cost of Engine Operation in California

Size of unit	Type of engine	B.P.H. per gallon fuel	Fuel cost per gallon	First cost per B.H.P.	Total first cost	Yearly fixed 20 per cent charge	Fuel cost 24 hours per day for 100 days	150 days	200 days	250 days	Total yearly charge, fuel plus fixed charges 100 days	150 days	200 days	250 days
		Cents	Cents	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars
50 H.P.	Distillates	10	5	25	1,250	250	600	900	1200	1500	850	1150	1450	1750
	Tops	10	$2\frac{3}{4}$	25	1,250	250	330	495	660	825	580	745	910	1075
	Semi-Diesel	10	$2\frac{1}{7}$	60	3,000	600	257	385	514	624	857	985	1114	1242
	Diesel	16	$2\frac{1}{7}$	75	3,750	750	160	241	321	401	910	991	1071	1151
100 H.P.	Distillate	10	5	30	3,000	600	1200	1800	2400	3000	1800	2400	3000	3600
	Tops	10	$2\frac{3}{4}$	30	3,000	600	660	990	1320	1650	1260	1590	1920	2250
	Semi-Diesel	10	$2\frac{1}{7}$	55	5,500	1100	514	770	1028	1284	1614	1870	2128	2384
	Hot-surface, high-economy	16	$2\frac{1}{7}$	65	6,500	1300	320	482	642	802	1620	1782	1942	2142
	Diesel	16	$2\frac{1}{7}$	75	7,500	1500	320	482	642	802	1820	1982	2142	2302
150 H.P.	Distillate	10	5	30	4,500	900	1800	2700	3600	4500	2700	3600	4500	5400
	Tops	10	$2\frac{3}{4}$	30	4,500	900	990	1485	1980	2475	1890	2385	2880	3375
	Semi-Diesel	10	$2\frac{1}{7}$	50	7,500	1500	771	1155	1542	1926	2271	2655	3042	3426
	Hot-surface, high-economy	16	$2\frac{1}{7}$	65	9,750	1950	480	723	962	1203	2430	2673	2912	3153
	Diesel	16	$2\frac{1}{7}$	70	10,500	2100	480	723	962	1203	2580	2823	3062	3303
250 H.P.	Distillate	10	5	30	7,500	1500	3000	4500	6000	7500	4500	6000	7500	9000
	Tops	10	$2\frac{3}{4}$	30	7,500	1500	1650	2475	3300	4125	3150	3975	4800	5625
	Semi-Diesel	10	$2\frac{1}{7}$	50	12,500	2500	1285	1925	2570	3210	3785	4425	5070	5710
	Hot-surface, high-economy	16	$2\frac{1}{7}$	60	15,000	3000	800	1202	1605	2005	3800	4202	4605	5005
	Diesel	16	$2\frac{1}{7}$	65	16,250	3250	800	1202	1605	2005	4050	4452	4854	5255

Yearly fixed charge is arrived at as follows:

Interest, 6 per cent; taxes and insurance, 1 per cent; repairs, 3 per cent; depreciation, 10 per cent.

Engine using distillate 48–51° Bé. oil has a thermal efficiency of 20 per cent under full load.

Engine using tops distillate 32-42 Bé. oil has a thermal efficiency of 20 per cent under full load.

Semi-Diesel engine using 24–28° Bé. oil has a thermal efficiency of 18 per cent under full load.

Hot-surface, high-economy engine using 16° Bé. oil has a thermal efficiency of 27 per cent under full load.

Diesel engine using 18° Bé. oil has a thermal efficiency of 28.4 per cent under full load.

Compiled by Messrs. Smith, Booth, Usher Co., in 1914

TABLE 22

*Test on Busch-Sulzer Bros. 225 B.H.P. Diesel Engine**

Number of test	1	2	3	4	5	6
Date of test	4-20-12	4-20-12	4-21-12	4-21-12	4-22-12	4-22-12
Duration of test, hours	3.00	3.00	3.00	3.00	3.00	3.00
KW. switchboard reading	.....	37.42	80.42	117.5	160	180.1
Comp. motor gross KW	.....	6.9	9.09	8.93	10	11.4
Net KW. output	.....	30.52	71.14	108.57	150	168.7
Efficiency of generator	.....	85%	87%	90%	92%	92.5%
Net B.H.P. load	2.25	49.7	111.39	162.97	219.63	245.6
Speed R.P.M.	171.1	169.1	167.4	164.4	164.8	161.9
Pounds cooling water per hour	3187	3037	4875	6300	4537	5175
Jacket inlet temperature °F.	61.8	62.4	61.9	62.6	61.7	66.7
Jacket outlet temperature °F.	115.3	127.9	115.5	118.9	156.6	173.1
Injection air pressure atmospheres	39	45.6	56	59	66	77
Fuel oil-pounds per net KW. hour	.....	1.25	0.7555	0.681	0.646	0.644
Fuel oil-pounds per net B.H.P. hour	.....	0.769	0.482	0.454	0.441	0.444
Fuel oil-gallons per 100 net B.H.P. hour	.....	10.8	6.8	6.4	6.2	6.2
Thermodynamic efficiency (based upon net useful output)	.....	17.4%	27.8%	29.5%	30.3%	30.2%

Analyses of the Exhaust Gases

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
	%	%	%	%	%	%
Carbon dioxide	1.50	3.05	3.92	4.70	6.46	8.40
Oxygen	18.42	16.03	14.95	14.70	9.93	8.93
"Illuminants"	0.00	0.00	0.00	0.00	0.00	0.00
Carbon monoxide	0.00	0.00	0.00	0.00	0.00	0.00
Methane	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen and water vapor	80.08	80.92	81.13	80.60	83.61	82.67
Totals	100.00	100.00	100.00	100.00	100.00	100.00

Analysis of Fuel Used

British thermal units	18,986
Specific gravity (25.5° C. to 27° C.)	0.8531
Viscosity 33.3° C. (92° F.)	1.63
Flash point	143.6° F.
Burning (fire) point	181.4° F.
Sulphur	0.2 per cent
Water	Trace
Free acid	None

*From Marine and Stationary Diesel Engine by A. H. Goldingham.

TABLE 23

*Test on 500 B.H.P. McIntosh–Seymour Cor. Diesel Engine**

Stroke $28\frac{3}{8}$ inches, Cylinder diameter $18\frac{3}{4}$ inches

Test No.	1	2	3	4	5
Date, 1915	Jan. 11	Jan. 11	Jan. 11	Jan. 11	Jan. 11
Load on brake, pounds	1651.5	1513.5	1150.0	750.0	370.0
Constant K	497.7	497.7	497.7	497.7	497.7
Number of R.P.M	171	165	172	174	170.
Brake H.P	567	502	397	262	126
Load, per cent	113.4	100.4	79.4	52.4	25.2
Time of test in hours	½	1	1	½	½
Fuel consumption during test, pounds.	115.0	204.7	163.8	58.9	41.1
Total fuel consumption per hour pounds	230.0	204.7	163.8	117.8	82.2
Fuel consumption per B.H.P. hour, pounds	0.405	0.407	0.412	0.449	0.652
Injection pressure, pounds per square inch	925	925	815	785	775
Exhaust gas appearance	Clear	Clear	Clear	Clear	Clear
Inlet temperature of cooling water, F°.	56°	56°	56°	56°	56°
Outlet temperature of cooling water, F°	145°	147°	145°	147°	150°
Temperature in testing room F°	62°	62°	62°	62°	62°

Analysis of Fuel Oil

Gravity	60° F. .8550
Baumé	60° F. 33°
Flashing point	190° F.
Burning point	246° F.
Viscosity at	68° F. 1.677 per cent
Tar test	Negative
Suspended matter	.005 per cent
Water	.051
Sulphur	.187
Distillation test—naphtha	1
Lamp oil	50.1
Lubrication	6
Heavy lubrication	42.5
Carbonization	6.4
Heat value	19,266 B.t.u.

* From Marine and Stationary Diesel Engines, by A. H. Goldingham.

Gasoline Engines

In the gasoline or petrol engine so extensively in use in automobiles, aeroplanes and motor boats, as well as for stationary installations, the feature probably of greatest interest is the carburetter, the function of which device, when attached to the suction or intake part of an internal combustion engine, is to receive air and liquid fuel and deliver to the cylinder of the engine an explosive mixture. The highly volatile products of petroleum, such as gasoline and petrol, are generally the fuels used, but kerosene is also vaporized in some devices of this description. Dugald Clerk [1] in referring to the principles of carburetion pointed out that for all internal combustion engines there is a " best mixture " giving for each engine maximum power and highest thermal efficiency, and it is the function of the carburetter to so vary the quantities of air and vapor that this " best mixture " is at all times and under all different running conditions properly maintained. The numerous designs of this apparatus have been classified and analyzed at great length in the reports of the National Advisory Committee for Aeronautics of the United States Government, and the theory of carburetion is very fully treated of in Vol. II of " Gas Petrol and Oil Engines " by Dugald Clerk, 1913, as well as in other treatises on this subject.[2] Brief reference will here be made to representative types of carburetters. Fig. 118 shows a single jet, raised needle, automatic type of carburetter which is in use on automobiles and in which the air valve controls the lift of the needle and automatically proportions the amount of gasoline and air at all engine speeds. The fuel flows by gravity to it, and on the various sectional views of this and other designs illustrated the various parts are clearly indicated.

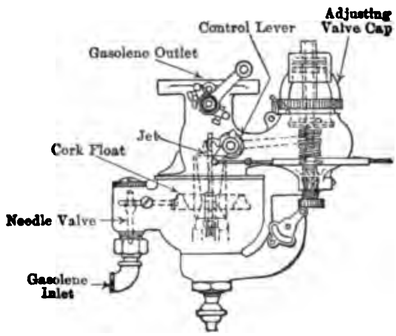


Fig. 118.—Schebbler carburetter (section).

The Standard Marine Gasoline engine, as manufactured by the Standard Motor Construction Company of Jersey City, U. S. A., is shown in section at Fig. 119. The six-cylinder design having 10-inch diameter and 11-inch stroke develops 220 B.H.P. at 460 R.P.M. It operates on the four-cycle plan and is direct reversing.

The sectional view shows the comparatively light yet rigid construction of the C. I. bed plate in which the main crankshaft bearings are fitted. It is connected to the cylinder casing and liner (cast in one piece) by forged tie-rods. The trunk piston, connecting rod and other details are also shown. The air-inlet valve, placed in the cylinder head, is automatic and is equipped with dashpot to produce noiseless operation. The exhaust valve, actuated by a cam in the usual way, is cast iron and internally water-cooled, the upper part of the valve is piston-shaped and has four piston rings inserted as shown. The method of reversing the direction of rotation of the crankshaft is that of longitudinal movement of the cam shaft to which is attached " ahead " and " astern " cams and ignition timing mechanism. Maneuvering is effected by compressed air furnished from the air compressor placed in line with the main cylinders and actuated from the crankshaft as shown in Fig. 119. The gasoline flows by gravity from the tanks to the float-box and strainer shown in Fig. 120, placed below the carburetter or

[1] Principles of Carburetter as Determined by Exhaust Gas Analysis, Dugald Clerk, Proc. Inst. A. E., 1907.

[2] Carburetion, by R. W. A. Brewer; Carburetters and Carburetion by Douglas Leechman; Petrol Motors and Petrol Cars by F. Strickland; Farm Gas Engines, by Herschfield and Ulbricht.

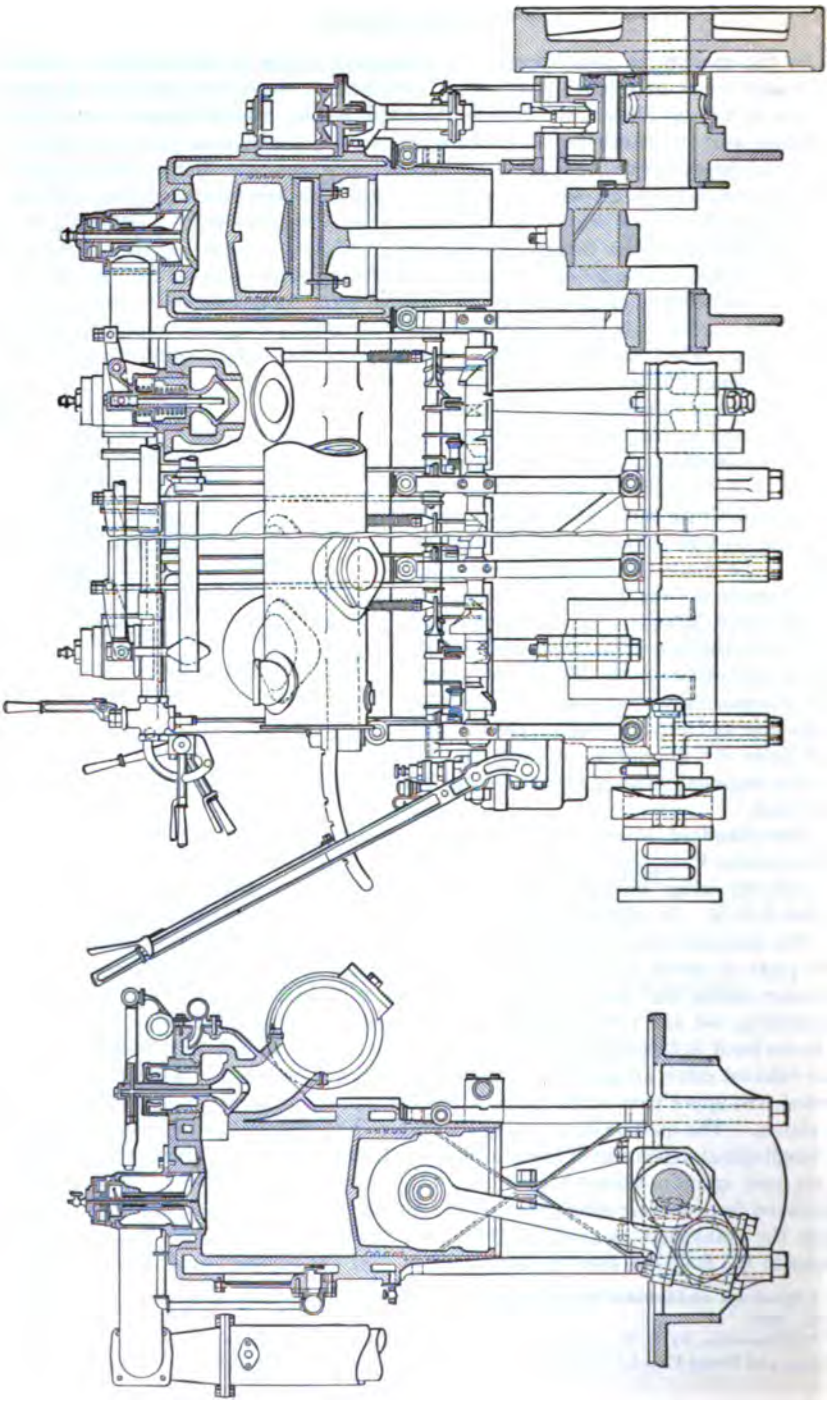


Fig. 119.—Standard Motor Co. gasoline engine.

vaporizer of the engine. The carburetter is of the constant-vacuum design, which automatically regulates the mixture of gasoline and air at all speeds. It is water-jacketed for circulation of heated water as shown in Fig. 121. In its mixing chamber are numerous sprayer tubes, each having a spraying nozzle and placed so that the shutter in its movement to and fro covers or uncovers such sprayers as are required. The sprayer shutter is worked automatically by the varying volume of air entering the intake pipe, being attached by connecting link to the piston of the vacuum chamber. The operator manipulates the throttle valve which also causes a variation in the vacuum chamber

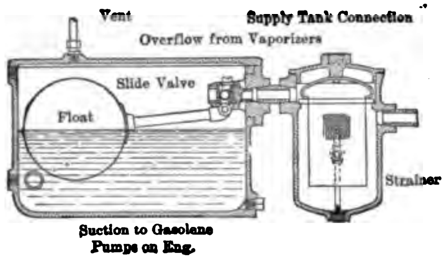


FIG. 120.—Standard Motor Co. float tank and strainer.

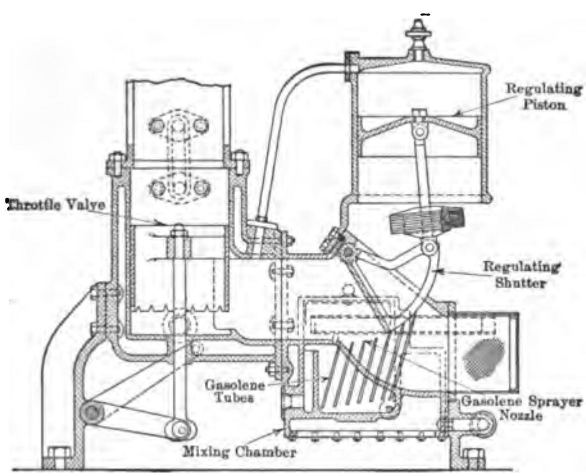


FIG. 121.—Standard Motor Co. carburetter.

with consequent movement of the shutter, which in turn varies the number of nozzles allowed to be exposed as may be required. The electric ignition is of the low-tension system, both magneto and battery being used, the latter for starting and "astern" movement, the former for "ahead" operation. The ignitor is of the "make-and-break" type actuated by the ignition cams for both "ahead" and "astern." Lubrication is accomplished by force-feed pumps furnishing lubricant to all moving parts. The cooling of the cylinders and other parts is caused by circulation of salt water supplied by the pump operated from the crankshaft by gearing and running at the speed of the crankshaft.

The Thomas Morse Liberty engine is illustrated in Fig. 122. Having six cylinders, each 5 inches in diameter and 7-inch stroke and operating at 1700 R.P.M., it develops 210 B.H.P. It operates on the four-cycle plan and is of the vertical, direct-drive, fixed-cylinder water-cooled type; its cylinders are of built-up steel construction with overhead valves and valve motion. The crankcase, made in two parts, is of an aluminum

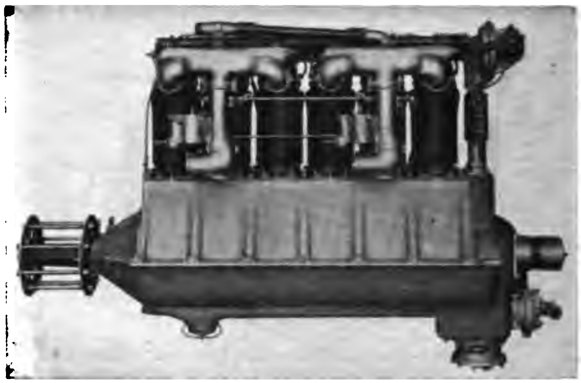


FIG. 122.—Thos. Morse Liberty engine.

alloy and contains the bearings for the forged steel crankshaft. The connecting rods are of " H " section forged steel with babbitt-lined split bronze bearings. The aluminum pistons each have three cast-iron piston rings. Each individual forged steel cylinder has forged steel valve housing and a two-piece steel stamping which forms the water jacket welded to it. Two spark plugs are inserted in bosses on each cylinder. Cooling water is circulated by a centrifugal pump placed at the rear end of the crankcase and

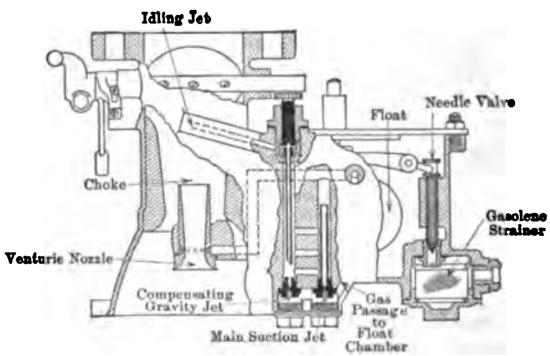


FIG. 123.—Thos. Morse Liberty carburetter (section).

actuated by the oil-pump shaft operated by bevel gears from the crankshaft. The zenith type carburetters placed on the left-hand side of the engine each feed three cylinders. Each carburetter has a main and compensating jet both delivering through a single Venturi nozzle at the center of the choke. For idling, a passage above the butterfly throttle valve is arranged with variable adjustment (see Fig. 123). Altitude control

consists of a small valve connecting the gasoline passage between the Venturi nozzle and the metering jets to the top of the float-chamber. A baffle plate placed in the manifold leading from the carburetter to each cylinder allows proper distribution of the vapor. The ignition is caused by a low-voltage generator and a small eight-volt storage battery; the former, placed in line with the crankshaft, furnishes current for general running, while the latter is required for starting only. The total weight of the engine is approximately 570 pounds.

Eagle Aero Engine manufactured by the Rolls-Royce Co. of England, is shown in Fig. 124. It has 12 cylinders 4½-inch diameter, 6½-inch stroke. Its weight is approximately 847 pounds and operating at 1800 to 2000 R.P M. maximum, 350 to

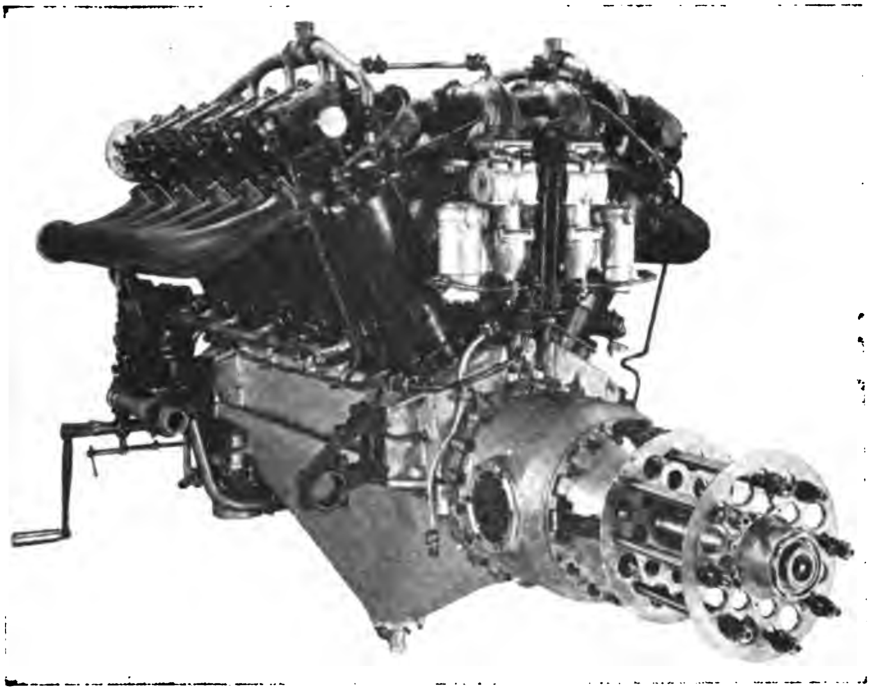


Fig. 124.—Eagle Aero engine R. R. Co.

365 H.P. is developed. This engine was used in the Vickers Vimy machines which crossed the Atlantic Ocean and in many other notable long distance flights and is considered, at the present time, a model of the very best design and construction. The arrangement of the cylinders is shown in Fig. 124. The one crankpin transmits the power of 2 cylinders; one connecting rod being articulated. The system of lubrication consists of a high-pressure circuit at 35 to 45 pounds per square inch lubricating chief moving parts, and a low-pressure circuit at approximately 2 pounds per square inch feeding overhead cam shafts, timing gears, and other parts.

The Claudel-Hobson Carburetter used on the above engine, is shown in section in Fig. 125. The diffuser consists of 3 concentric tubes, the upper end of which comes within a short distance of the head. The fuel level stands below the top of the guard tube and varies as the velocity of the air, through the choke, increases; such holes

as are required being uncovered in the depression tube and admitting more air. The ratio of petrol and air is thus maintained for varying engine speeds. The various parts of this apparatus are described in the explanatory paragraph below the illustration.

AUTOMOBILES

The automobile or motor-road vehicle is built either (*a*) for passenger service, which is of light construction built for speed and comfort, or (*b*) for commercial vehicles constructed for transporting heavy loads and to travel at comparatively slow speeds. If classified according to their propelling power plants, they are (*a*) steam, (*b*) electric, (*c*) gasoline or gasoline-electric. The vehicle propelled by the

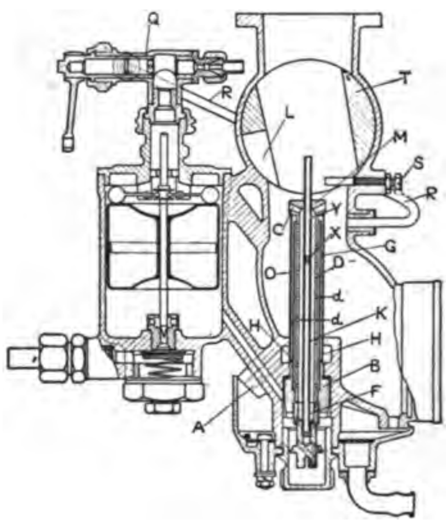


FIG. 125.—Claudel Hobson carburetter. (*D*) Depression tube having numerous drilled holes (*dd*). (*B*) Plug in carburetter body carrying main jet (*J*). (*G*) Guard tube. (*M*) Emulsion head with holes (*C*). (*H*) Connecting holes to atmosphere at base of tube (*O*), and air holes (*A*). (*K*) Slow-running jet. (*T*) Throttle barrel having slot (*L*) forming choke around pilot jet when throttle is closed. (*S*) "Air screw" for adjusting strength of mixture when running slow. (*A*) Air hole. (*O*) Outer tube. (*F*) Holes at base of jet. (*X*) Restriction regulating amount of fuel passing. (*Y*) Air admission holes. (*Q*) Three-way cock. (*R*) Fuel connection.

gasoline internal-combustion engine is now most generally in use and of greatest interest. It will be briefly referred to here. The subject is treated at great length and in detail in many works devoted to this subject. For example: The Gasoline Automobile by P. M. Heldt; The Modern Gasoline Automobile by V. W. Page; Text Book on Motor Car Construction by Clark; The Gasoline Automobile by Hobbs, Elliott and Consoliver; and Putnam's Automobile Handbook.

The Chassis of a representative pleasure car consists of (*a*) the frame usually composed of channel section pressed steel; (*b*) the engine, which is built of both the two- and four-cycle type operating with processes of valve movements similar to those described on page 529. It is provided with carburetter, electric ignition system, cooling and lubrication systems; (*c*) friction clutch necessary to disconnect the engine shaft from the driving mechanism, thus eliminating the necessity of stopping the engine

each time the car is stopped; (*d*) speed change or transmission gear allowing various speeds of travel independent of the engine speed; (*e*) rear axle with its differential gear allowing each rear driving wheel to revolve at different speeds when necessary; (*f*) the front axle with its requisite steering-gear devices; (*g*) springs; (*h*) wheels; (*i*) speed control lever assembly; (*j*) jointed propelling shaft with universal joints; (*k*) fuel tank and piping; and (*l*) the radiator for cooling.

Engine.—The general theory of the operation of the gasoline motor conforms to that outlined on page 527. For commercial vehicles the four-cylinder design is more frequently used. For the pleasure car, motors have four, six, eight or more cylinders. The cylinders composed of gray cast iron and provided with ample water-circulating space on the upper part are made in pairs or cast in one block of four. With the four-cycle type (most generally in use) the air inlet and exhaust valves are all placed either on one side of the cylinder head or the air inlet is found on one side and the exhaust valves on the other side. The trunk piston is provided with three or four cast-iron piston rings and internal bosses for carrying the gudgeon pin somewhat similarly to the construction outlined previously for the heavy oil engine. The connecting rod, generally of I section drop-forged steel, is equipped with a bronze bushing at its piston end and an adjustable bearing at its crank end.

The lift of the poppet-air inlet and exhaust valves is restricted to allow noiseless operation usually being $\frac{1}{4}$ its diameter plus $\frac{1}{8}$ inch. Carburetters have already been referred to on page 615 and of the numerous types in use representative examples have been there described and illustrated. The various diagrams of valve movements shown of the oil and Diesel engines do not apply to the automobile engine. Here the periods of opening and closing vary in different designs and the opening of the air-inlet valve in many four-cycle types does not commence till the crankpin has reached 10° to 15° past the inner dead center and remains open till approximately 30° past the outer dead center. The exhaust valve opens about 45° before the crankpin reaches the outer dead center and closes about 10° after the inner dead center is passed by the crankpin. The ignition of the explosive mixture in the cylinders is caused by different methods, in some types from high-tension magnetos which furnish the current in ordinary operation with the current supplied from batteries at starting. The igniting spark plugs are inserted in the spark-plug shell screwed into or near the inlet-valve cap. Detailed descriptions of the different ignition systems will be found in the treatises already referred to.

Horse-power Formulae of the Society of Automotive Engineers

Four-stroke Cycle Engines

	Authority	Formula
1.	N. A. C. C. (Formerly A. L. A. M.) Royal Auto. Club	$\frac{D^2N}{2.5} = \text{H.P.}$
2.	Brit. Inst. of Auto. Engrs.	$0.45(D+L)(D-1.18) = \text{H.P.}$
3.	E. P. Roberts	$\frac{D^2LRN}{18{,}000} = \text{H.P.}$

D = diameter of cylinder in inches;

L = length of stroke in inches;

R = revolutions per minute of crankshaft;

N = number of cylinders.

Derivation of the N. A. C. C. (formerly A. L. A. M.) Horse-power Formula

The indicated horse-power of a single-cylinder, four-cycle engine is equal to one-quarter times the mean effective pressure P, acting throughout the working stroke, times the area of the piston A, in square inches, times the piston speed S divided by 33,000, thus:

$$\text{I.H.P.} = \tfrac{1}{4}\frac{PAS}{33{,}000}.$$

Multiplying this by the number of cylinders N gives the I.H.P. for an engine of the given number of cylinders, and further multiplying by the mechanical efficiency of the engine E gives the brake horse-power. Therefore the complete equation for B.H.P. reads:

$$\text{B.H.P.} = \frac{PASNE}{33{,}000 \times 4}.$$

The A. L. A. M. assumed that all motor-car engines will deliver or should deliver their rated power at a piston speed of 1000 feet per minute, that the mean effective pressure in such engine cylinders will average 90 pounds per square inch, and that the mechanical efficiency will average 75 per cent.

Substituting these values in the above B.H.P. equation, and substituting for A its equivalent, $0.7854D^2$, the equation reads:

$$\text{B.H.P.} = \frac{90 \times .7854D^2 \times 1000 \times N \times .75}{33{,}000 \times 4},$$

and combining the numerical values it reduces to:

$$\text{B.H.P.} = \frac{D^2N}{2.489},$$

or, in round numbers, with a denominator 2.5.

Nominal Tractor Engine and Drawbar Ratings

(General information only)

The following tractor horse-power formula was developed by the 1919 Tractor Division, but was not adopted by the S. A. E., as it is considered a commercial rather than an engineering formula:

$$\text{Nominal engine horse-power} = \frac{0.7854D^2LRN}{13{,}000},$$

where D = piston diameter in inches;
L = stroke in inches;
R = R.P.M. of crankshaft;
N = number of cylinders.

The formula is based on a piston displacement of 13,000 cubic inches per minute per horse-power, as this is considered the best average factor for stationary and tractor-engine practice. The formula is considered satisfactory for tractors and stationary engines burning either kerosene or gasoline, although various mechanical arrangements would influence actual results.

The results obtained using this formula are almost exactly 80 per cent of the brake horse-power under average good conditions, which provides the desired 20 to 25 per

cent of reserve power. It is not intended that this empirical formula shall be used in engineering calculations.

The tractor drawbar rating developed is 50 per cent of the nominal tractor engine horse-power rating.

$$\text{Tractor drawbar rating} = \frac{0.7854 D^2 LRN}{26{,}000}.$$

The drawbar pull in pounds may therefore be expressed by the following formula:

$$\text{Drawbar pull} = \frac{\text{Rated drawbar horse-power} \times 375}{\text{miles per hour}}.$$

Automobiles in Use in the United States

Automobiles in Use in the United States

The registration of automobiles, motor trucks and other vehicles for the year 1920 does not indicate the exact number of such in actual use in the United States, but it furnishes a very reliable index of the total number of cars in each state as shown in Table 24.

Motor Vehicle Registrations, 1915 to 1920 *

	Motor Car Registration [1]					
	1915	1916	1917	1918	1919	1920
Alabama	11,634	21,636	32,873	46,171	58,898	74,637
Arizona	7,753	12,300	19,890	23,905	29,575	34,601
Arkansas	8,021	15,000	28,693	41,458	49,450	59,082
California	163,797	232,440	306,916	407,761	477,450	583,623
Colorado	28,894	43,296	87,460	83,244	104,865	129,255
Connecticut	41,121	56,048	74,645	86,067	102,410	119,134
Delaware	5,052	7,102	10,700	12,955	16,152	18,300
District of Columbia	8,009	13,118	15,493	30,490	35,400	34,161
Florida	[2] 10,850	20,718	[3] 27,000	54,186	55,400	73,914
Georgia	25,000	46,025	70,324	104,676	137,000	146,000
Idaho	7,071	12,999	24,731	32,289	42,220	50,861
Illinois	180,832	248,429	340,292	389,620	478,438	568,924
Indiana	96,915	139,065	192,194	227,160	227,255	333,067
Iowa	145,109	198,587	254,462	278,313	364,043	437,378
Kansas	72,520	112,122	159,343	189,163	228,600	294,159
Kentucky	19,500	31,500	47,420	65,884	90,008	112,683
Louisiana	11,380	17,000	28,394	40,000	51,000	73,000
Maine	21,545	30,972	41,499	44,572	53,425	62,907
Maryland	31,047	44,245	60,943	74,666	95,634	102,841
Massachusetts	102,633	136,809	174,274	193,497	247,182	274,498
Michigan	114,845	160,052	247,006	262,125	325,813	412,717
Minnesota	93,269	[4] 46,000	[5] 54,009	204,458	259,741	324,166
Mississippi [3]	9,669	25,000	36,600	48,400	59,000	68,486
Missouri	76,462	103,587	147,528	188,040	244,363	297,008
Montana	14,540	25,105	42,749	51,053	59,324	60,650
Nebraska	59,000	101,200	148,101	173,374	200,000	219,000
Nevada	2,009	4,919	7,160	8,159	9,305	10,464
New Hampshire	13,449	17,508	22,267	24,817	31,625	34,680
New Jersey	81,848	109,414	141,918	155,519	190,873	227,737
New Mexico	5,100	8,228	14,086	17,647	18,082	22,100
New York	255,242	314,222	406,016	459,292	566,511	676,205
North Carolina	21,000	33,904	55,950	72,313	109,017	140,860
North Dakota	24,908	40,446	62,993	71,678	82,885	90,840
Ohio	181,332	252,431	346,772	412,775	511,031	621,390
Oklahoma	25,032	52,718	100,199	121,500	144,500	212,880
Oregon	23,585	33,917	48,632	63,324	83,332	103,790
Pennsylvania	160,137	230,578	325,153	394,186	482,117	570,164
Rhode Island	16,362	21,406	37,046	35,218	44,833	50,477
South Carolina [2]	15,000	[6] 25,000	38,332	55,492	70,143	93,843
South Dakota	28,724	44,271	67,158	90,521	104,628	120,395
Tennessee	[7] 7,618	[3] 30,000	48,000	63,000	80,422	101,852
Texas [2]	40,000	[6] 125,000	192,961	251,118	331,310	427,693
Utah	9,177	13,507	24,076	32,273	35,236	42,616
Vermont	11,499	15,671	21,633	22,553	26,807	31,625
Virginia	21,357	35,426	55,661	72,228	94,100	115,470
Washington	38,823	60,734	91,337	117,278	148,775	173,920
West Virginia	13,279	20,571	31,300	38,750	50,203	80,664
Wisconsin	79,741	115,645	158,637	196,253	236,290	293,298
Wyoming	3,976	7,125	12,523	16,200	21,371	23,926
Total	2,445,664	3,512,996	4,983,340	6,146,617	7,565,446	9,231,941

* Reprinted from "Public Roads," Vol. 3, No. 25.

[1] Does not include motor cycles nor dealers' and manufacturers' licenses.

[2] State registrations only. [3] Estimated.

[4] Cars registered during 1916; total number of cars, approximately 138,000.

[5] Cars registered, 1917. [6] Estimated number of cars in State.

[7] Registrations 1915 only.

LUBRICATION

BY

JOHN D. GILL

INTRODUCTION

How to select a lubricant for a given set of conditions is the principal theme of this chapter. It is believed that only that part of the subject of lubrication which is susceptible of mathematical analysis, or at least of approximately quantitative discussion, has much practical application and, therefore, deserves a place in this volume. It is assumed that the reader is familiar with the science of mechanics, especially with the subject of friction, is acquainted with the operation of machinery, has a knowledge of engineering test methods and is cognizant of the importance of lubrication as a matter of practical national economics.

Confusion in the selection of lubricants has arisen from three causes: (1) The quantitative significances of the various factors involved, though clearly defined in the theoretical treatises, have not been practically applied. (2) The variety of factors has made it difficult to "weight" their relative importance and combine the "weighted significances" to arrive at a conclusion which could be expressed in terms of the principal characteristics of the lubricant. (3) Insignificant factors have been permitted to cloud the main issues. An attempt will be made in what follows to eliminate all causes of confusion. In the case of the last named cause, this will be accomplished by omitting unimportant matters from consideration.

> There is no reason to hesitate longer in the expression of a rational formula for the selection of lubricating oils, particularly bearing oils, if we are willing to accept approximations based on good theoretical considerations and practical experience—approximations which answer the requirements of lubrication quite as satisfactorily and as accurately as the approximations employed in the design and construction of the machine to be lubricated.

Stated in more detail, the purpose of this chapter is to set down:

1. Definite rules to enable an engineer to make suitable selections of lubricants for any of a large range of operating conditions.[1] Methods of selection described are based on the known laws of lubrication and on successful experience, and apply primarily to the common types of power-plant and shop machinery. The principles given are, however, applicable to special machinery, e.g., silk-spinning spindles revolving up to 15,000 R.P.M., in the lubrication of which the hazard of the splash of very fluid

[1] The problem of the lubricating engineer is to lubricate machinery—rotating bearings, reciprocating bearings, etc.—as it is found, accepting as a matter of course, the imperfections of machine parts, due to poor design, poor construction or careless operation. He cannot reconstruct the machine. Occasionally he may find it necessary to change the methods of application of the lubricant; and by the nature of his experience is in position to point out needed changes in design of the rubbing parts of machinery.

oil out of the bearing upon the fabric becomes of more importance than the economic factors of wear and tear on machinery and of the loss of power.

2. Some typical examples of the practical solution of lubrication problems.

3. Reference to the literature of lubrication as a guide to the further study of related problems, to original experiments and to theoretical treatises. (See page 678.)

RELATIONSHIPS WHICH GOVERN SELECTION

Unless the mechanical factors of lubrication, e.g., bearing pressures, rubbing speeds, bearing clearances, etc., are discussed quantitatively in their relation to the selection of correct viscosity, the discussion has little or no practical value. Non-mechanical factors of lubrication, by way of present illustration, include the ability of the lubricant to separate quickly from water in which it is suspended.

However, it suffices to *approximate* the quantitative relationships of the several factors; rigid mathematical analyses are more refined than the conditions ordinarily met in practice warrant.

We must begin the science of lubrication by practicing the art of lubrication.

The quantitative relationships should enable us better to understand the physical facts.

For the foregoing reasons the quantitative relationships discussed herein will approximate the facts closely enough for all engineering demands.

An understanding of the physical significance and definite mechanical characteristics of the viscosity of liquids in terms of engineering units (feet, pounds, minutes), is essential to the solution of problems of selection of lubricants.

Suppose a film of oil 0.002 inch thick and 120 square inches in area to lie between two smooth parallel plates, the lower of which is fixed and the upper one susceptible to linear movement by a force which is measurable by a spring dynamometer, and that the temperature is held constant. Suppose, further, that the movable plate is pulled with a velocity of 2½ feet per second and the dynamometer indicates a force of 13 pounds. This force of 13 pounds is a direct measure of the viscosity of the oil, i.e., the magnitude of the resistance to motion offered by the particles of which the oil is made. If the oil film had been only 0.001 inch thick the force would have been 26 pounds. Or, if the area had been only 60 square inches, or the speed only 1¼ feet per second, the force would have been only 6½ pounds. The force of resistance of the oil is inversely proportional to the thickness of the film, and directly proportional to the area of the film and to the speed of motion.

In the case above, the viscosity of the oil, in terms of the scientific or c.g.s. (centimeter, gram, second) system of units is 0.5 dyne per square centimeter. This is equivalent to a viscosity of about 256 on the Saybolt Universal Standard Viscosimeter as measured by this instrument in seconds of flow (see Chapter on Testing) regardless of temperature, the specific gravity of the oil being taken as 0.90.

Viscosity is a definite physical property of a liquid, being essentially the resistance which the particles of the liquid offer to a force tending to move them relatively. This viscous resistance can be measured in terms of pounds of force. When the viscous resistance in pounds is known, together with the film thickness and area, and speed of motion, it can be converted into "absolute" viscosity (c.g.s. system of nomenclature) or the exact scientific measure of viscosity; and the absolute viscosity, in turn, can be converted into terms of our ordinary laboratory methods of measuring viscosity.

The measure of viscosity of a liquid, or for our purpose, the resistance, in pounds, offered to the relative motion of two parallel, or nearly parallel, surfaces, separated

by the liquid which adheres to both surfaces, is expressed by the following formula, which converts "absolute" into "engineering" viscosity:

$F = 0.00291$ pound for each *square inch* of oil film separating the surfaces and affected by the relative motion; for each *foot per minute* of relative motion; for an oil film 0.001 inch thick, of unit "absolute" viscosity as measured by the c.g.s. system.

Or,

Resistance (pounds) = 0.00291 × area (square inches) × motion (feet per minute) × viscosity (absolute or c.g.s.) ÷ film thickness (thousandths of an inch).

We may define the engineering "unit of viscosity" as that viscosity which offers a resistance of 0.00291 pound to the relative motion, at the rate of 1 foot per minute, of opposite faces of a film of the viscous liquid, 1 square inch in area and 0.001 inch thick. On this basis, the viscosity of an oil making a film 0.001 inch thick over an area of 2 square inches between two surfaces moving relatively 1 foot per minute would be 0.00582 pound. Or, an oil of one-half the unit viscosity would offer a resistance of 0.001455 pound for the standard conditions given.

The surfaces of a journal and its bearing, for the condition of perfect lubrication, may be looked upon as two nearly parallel (for the concentric condition which obtains at very high speeds, they are parallel) surfaces separated by a film of oil, of appreciable thickness, which adheres to the surfaces, the surfaces moving relatively with the velocity of the circumferential speed of the journal.

Disregarding the influence of the passage of oil in and out of the bearing, and of eccentricity of the journal and bearing, and assuming that the average thickness of the oil film is one-half the bearing clearance, the formula for the resistance to the motion of a journal offered by an oil of unit viscosity is:

$$F = \frac{0.0024ND^2L}{\frac{\text{Clearance}}{2}},$$

in which N = speed of the journal in revolutions per minute;
D = diameter of the journal, in inches, and
L = length of the journal, in inches.

For the foregoing conditions the frictional power loss of the bearing will be:

$$\text{Horsepower} = \frac{0.000,000,01904N^2D^2L}{\frac{\text{Clearance}}{2}}.$$

For straight-line motions, e.g., pistons and crossheads, the formula for resistance or frictional force is:

$$F = \frac{0.00291 \times A \times S}{t},$$

in which F = frictional resistance in pounds for unit of absolute viscosity;
A = film area in square inches;
t = average film thickness in thousandths of an inch;
S = relative motion of surfaces in feet per minute.

Frictional resistance, or power loss, in each of the foregoing formulae for a viscosity other than unity, is obtained by multiplying the right side of the equation by the number of units of absolute viscosity.

Fig. 1 represents graphically the relation between "absolute" viscosity and Saybolt Universal viscosity. Fig. 2 gives the conversion of "absolute" viscosity into engineering units of pounds, feet and minutes.

In the case discussed on page 626 the performance of work was at the rate of $\frac{13 \text{ pounds} \times 2\frac{1}{2} \times 60 \text{ feet per minute}}{33{,}000 \text{ foot-pounds per minute}}$ or 0.065 horse-power. The conditions approximate those for a journal 4 inches in diameter and 10 inches long, revolving concentrically with the bearing, with a radial clearance of 0.002 inch, at a speed of 150 R.P.M.,

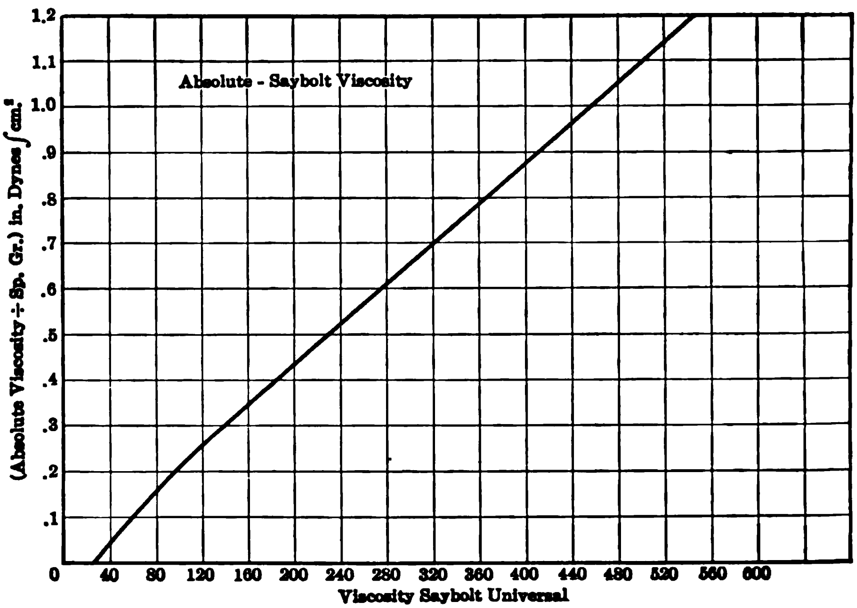


FIG. 1.—Absolute viscosity. Scientific units.

supplied with sufficient oil of 256 seconds Saybolt viscosity to maintain a perfect film between the journal and bearing.

Suppose we place a weight of 12 pounds on the movable plate and manage somehow to keep the film area, temperature and thickness the same. The force required to draw the plate 150 feet per minute will still be 13 pounds. Indeed, so far as is known, we may weight the plate to 120 pounds or 1200 pounds, or to a load equivalent to a unit pressure of several thousand pounds per square inch, and so long as we maintain the film area, temperature and thickness constant the frictional force will remain practically the same. This load-carrying ability probably follows the law of the compressibility of liquids.

In our ordinary experience we find, however, that the load forces the oil from between the plates; the heavier the weight, the faster the expulsion of oil; likewise the lower the viscosity of the oil the faster it is expelled. For the same basic reason, the higher the viscosity of the oil the greater the resistance offered to the motion, and the slower the rate of expulsion from the bearing.

Suppose, further, that a feeding device were arranged to maintain the original quantity of oil between the plates, keeping the film of constant area and thickness. It is obvious that the force required for motion at the given speed will remain constant. The additional factor, "rate of feed," has entered the problem.

These several factors, properly expressed, constitute the elemental laws of lubrication for the condition of complete separation of bearing surfaces by a film of appreciable thickness (which is the only condition which should be countenanced to-day in the operation of machinery).

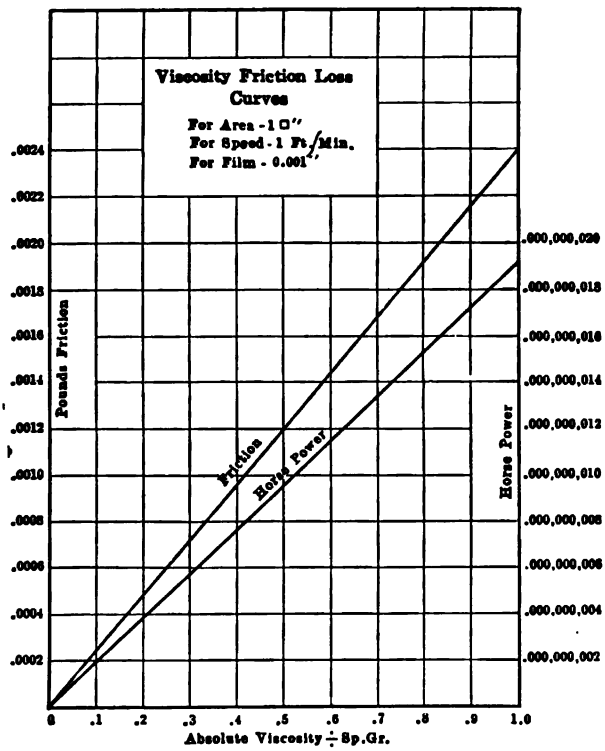


FIG. 2.—Viscosity relations. Engineering units.

It is appreciated that there are other factors which would have to be considered in a complete mathematical treatise; but the effect of some of these factors is, for engineering purpose, negligible, and the quantitative effect of others, assumed to be of low magnitude, is unknown. It is believed that the influential factors are considered in the discussion.

For all practical engineering purposes, the laws of lubrication are expressed with sufficient accuracy as follows:

1. The force of friction increases directly with the true or absolute viscosity of the lubricant.

2. The force of friction increases directly with the area of the lubricating film.

3. The force of friction increases directly with the linear speed of relative motion of the lubricated surfaces.

4. The force of friction increases inversely as the thickness of the lubricating film.[1]

5. The force of friction is practically unaffected by the pressure placed upon the film, if the film is kept constant in thickness, area, and viscosity.[2]

6. Loss of lubricant from between the surfaces is nearly directly proportional to the effective unit pressure on the bearing and versely proportional to the true viscosity of the lubricant, particularly for thick films (large bearing clearances.)

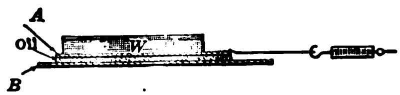


Fig. 3.—Oil dynamometer.

There are no laws governing the relation between friction and the several other factors in cases in which the lubricated bearings have metallic contacts with their journals. For such bearings, friction is variable and generally excessive.

The laws relating friction with viscosity, area of film, thickness of film, linear speed and load have been roughly approximated in experiments with plates (Fig. 4), made under the direction of the writer. More elaborate experiments, extending over a period of months of continuous work were made by the writer on a specially designed bearing-friction machine, shown in the illustration (Fig. 9).

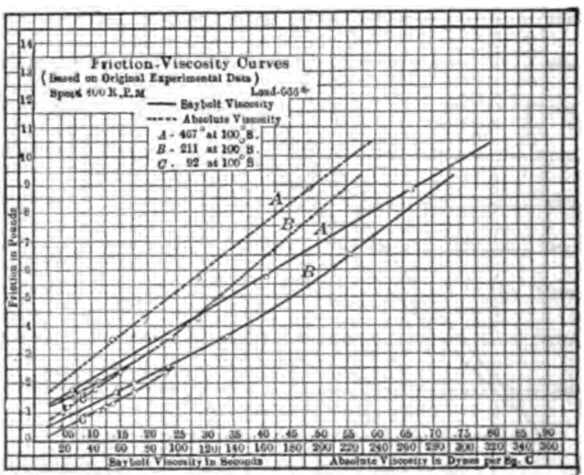


Fig. 4.—Experimental viscosity. Friction relations.

This machine was capable of a range of speeds from 60 to 960 feet per minute, of pressures from zero to 666 pounds per square inch, of temperatures from that of faucet water to upwards of 200° F. When operating under best conditions it had a sensibility of 0.1 inch-pound (the frictional moment at the circumference of a 2½-inch diameter shaft). Frictional values obtained with this machine in the spring of 1913 under a given set of conditions, were checked in the autumn of the same year by

[1] Combining laws 1 and 4, it is evident that we may have a combination of high viscosity and large clearance which will result in less friction than a combination of low viscosity and very close fit.

[2] The latest researches indicate that the viscosity of liquids increases with pressure, for mineral oils the increase being approximately 30 per cent for a pressure increase from zero to 2000 pounds per square inch, and directly proportional to the pressure increase. See the Report of the Advisory Council of the British Department of Scientific and Industrial Research.

the same operator working under the same set of conditions and with the same oil, to within an error of 5 per cent.

Fig . 4 to 8, drawn from experimental data, and Figs. 10 and 11 illustrate the laws of lubrication and their supplements. The curves do not portray the laws with precision because of experimental errors. However, the experimental data approximate the laws which have been mathematically derived, with sufficient closeness to

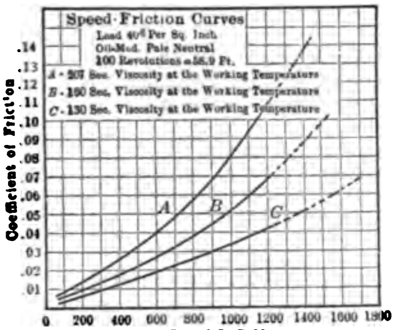


FIG. 5.—Experimental speed. Friction relations at constant temperature.

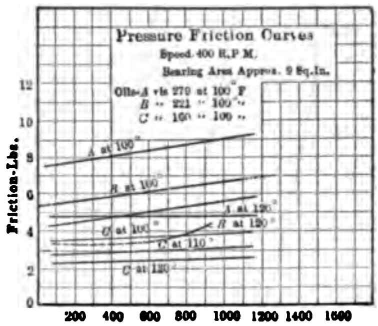


FIG. 6.—Experimental pressure. Friction relations.

be a reasonable experimental verification of them. Furthermore, in practice, because of conditions which cannot be studied so closely as in the laboratory, e.g., " clearance," " live load," etc., approximations within a reasonable limit of error are the best that we can hope for. If these principles are fully recognized it is feasible to proceed to the solution of problems in the selection of " viscosity " with the degree of assurance common to engineering practice.

The following are important supplements to the foregoing principles.

Viscosity of oil lubricants decreases rapidly with increasing temperature. Therefore, selections of viscosity must be made with reference to the temperature to which the lubricant will be subjected and not simply to an arbitrary " testing " temperature.

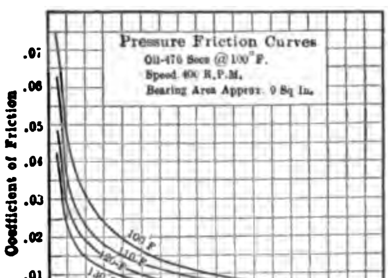


FIG. 7.—Change of coefficient of friction with pressure.

Influence of the arc of contact.—Goodman found that the friction decreased when the arc of contact decreased, being roughly one-third as much at 29° as at 180°.

Bearing metals.—With complete film lubrication the practical influence of the materials of journals and bearings on friction is negligible, there being no appreciable differences between hard, mild and nickel steel journals using white metal bearings. Little difference was found between white metal, soft amalgam alloys and gun metal bearings with nickel-steel journals.[1]

Tests by O. Lasche [2] with journals of open-hearth machinery steel, tool and nickel steel and with bearings of white metal and gun metal gave the same frictional values,

[1] From "Friction and Lubrication," Professor G. F. Charnock, Mechanical World, 1906, p. 362.
[2] Eng. Mag., Vol. 24, March, 1903, pp. 915-17.

showing that the *material* of the rubbing surfaces does not constitute a factor in frictional values.[1]

Within the limits of their abrasion, various metals have nearly the same friction.[2]

Breakdown (Critical) Pressures.—Fig. 12 shows the method of determining the breakdown (critical) viscosity for a given bearing load. The critical viscosity is taken

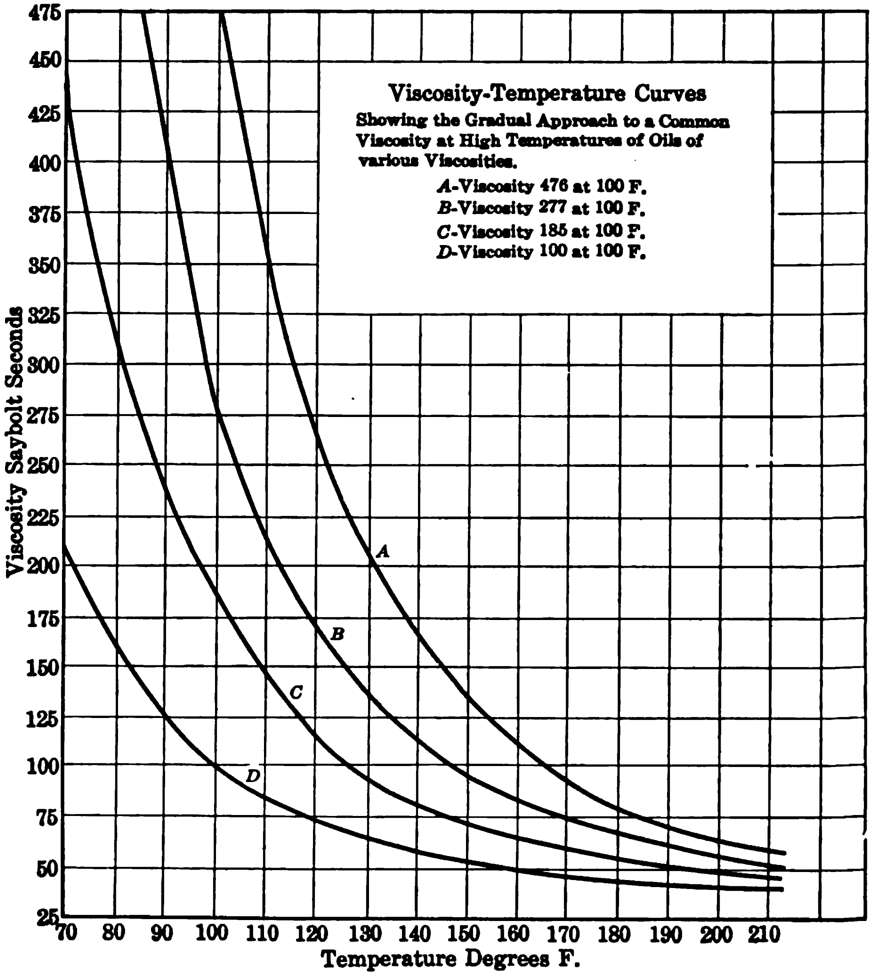


FIG. 8.—Change of viscosity with temperature. "Bearing" oils.

at the point at which friction changes from "decreasing" to "increasing," as the viscosity was decreased—conditions of load, speed and feed remaining constant. In the series of experiments from which Fig. 12 was taken, the increase in friction was not sufficient to cause serious abrasion of the bearing but did indicate a decided weakening of the oil film.

[1] Eng. Mag., Vol. 24, March, 1903, pp. 915–17.
[2] George Rennie, Philos. Trans,. Vol. 119, 1829, pp. 143–170.

The Composite Breakdown Curve, Fig. 13, shows the general relation between viscosity and breakdown pressures for the particular conditions of speed, etc., given. From previous experiments it was determined that the feed was ample to supply the bearing with lubricant to equal that normally·expelled; breakdown is, therefore, construed as resulting from lack of the viscosity needed to wedge into the bearing at the point of the minimum film thickness, resulting in a gradual and alarming thinning of the film. Whether abrasion occurs or not, breakdown viscosity is regarded as that viscosity at which the film becomes dangerously thin. Factors of safety, to be given hereafter, are calculated for critical pressures determined in this way. Here

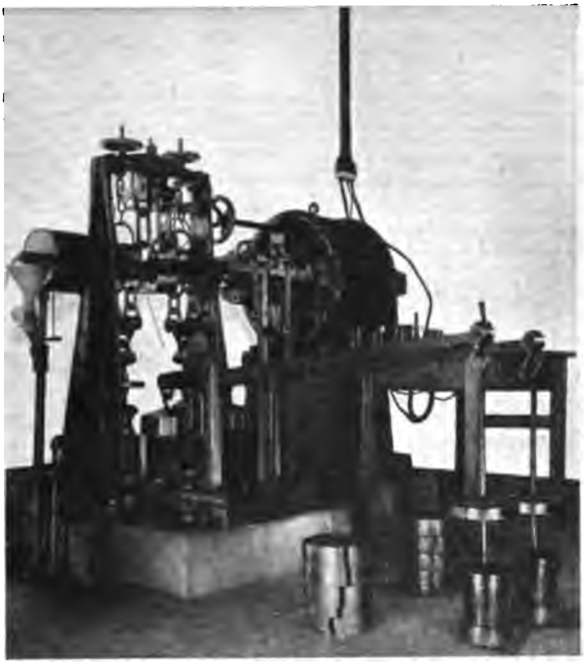


FIG. 9.—Bearing-friction testing machine.

again, the omission of mathematical refinements is entirely in harmony with our determinations of influential factors, which at best are but approximations.

One point which stands out very clearly is that lubricating oils of permanent character have a remarkable load-carrying power and that the factors of safety we have been using, more or less unconsciously, have frequently been excessive.

NOTE.—"The limit of safe load for complete lubrication is that which causes the least separating distance to be one-half the difference in radii of the journal and bearing."[1]

According to Somerfeld and Hershey the minimum coefficient of friction occurs at a film thickness equal to 0.29 of the clearance.

Oil film pressure.—"The oil film does not immediately form even with an abundant supply of lubricant; and between the time of starting and until the oil film is established there is friction between the solid surfaces, and there is some wear of the brasses. If,

[1] Professor Osborne Reynolds, "On the Theory of Lubrication and Its Application to Mr. Beauchamp Tower's Experiments": Proceedings of the Royal Society, Vol. XL, pp. 191–203, 1886.

on the other hand, the supply of oil is limited when starting, the oil film will sometimes take hours to form, forming and breaking alternately." [1]

The pressure of the oil film at the center of the bearing increases faster than the load.

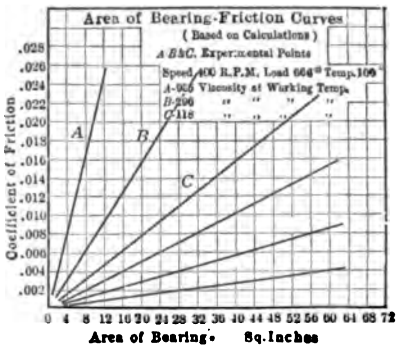


FIG. 10.—Effect of area of rubbing on friction.

Load, pounds per square inch	Oil film pressure, pounds per square inch
50	57
100	160
150	252
200	325
250	405
300	480
350	525
400	600

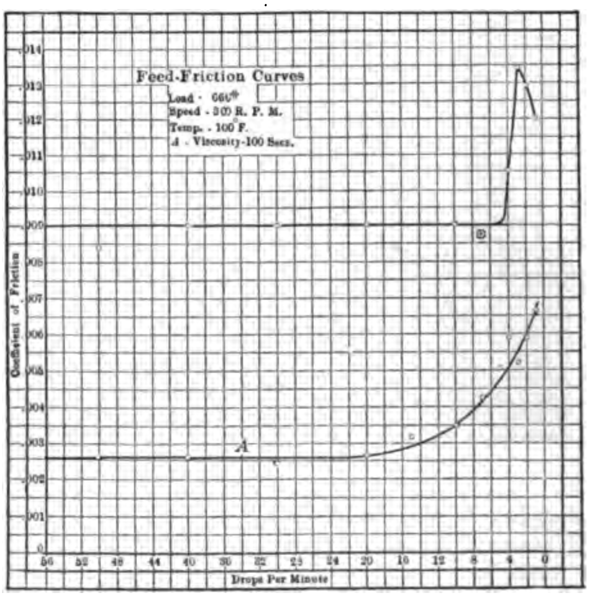


FIG. 11.—Feed-friction relations, for determination of minimum feed for perfect film lubrication.

EFFECT OF SPEED ON ABILITY OF VISCOSITY TO CARRY LOADS

The relation between the breakdown pressures and the velocities of rubbing has been determined experimentally for certain conditions by H. F. Moore. Pressure varies as the square root of the rubbing velocity; for some conditions the allowable pressures vary nearly with the velocity.

[1] Lieut. G. J. Meyers, Friction and Lubrication: Proc. A. S. Nav. Engs., p. 500, May, 1911.

Professor Moore's formula, applicable to a very specific set of conditions is:

$$P = 7.47\sqrt{v},$$

in which P = bearing pressure in pounds per square inch of projected area;
v = rubbing velocity in feet per second.

Modifying the formula for more general application, we have:

$$P = K \times 7.47\sqrt{v},$$

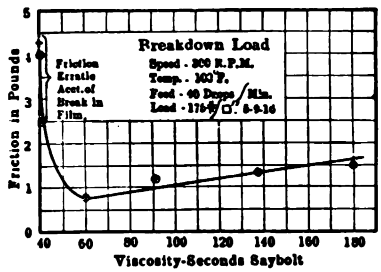


Fig. 12.—Illustrating method of determination of critical bearing loads.

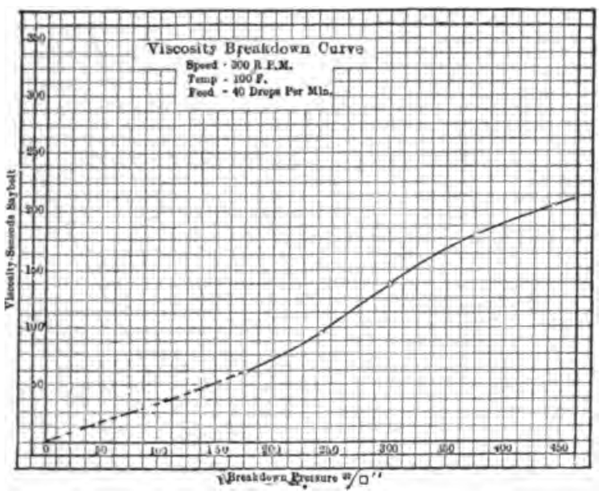


Fig. 13.—Critical relations between viscosity and bearing pressure.

in which K is a constant for any given viscosity, P and v, being variable at will. Further generalizing:

$$P = K\sqrt{v},$$

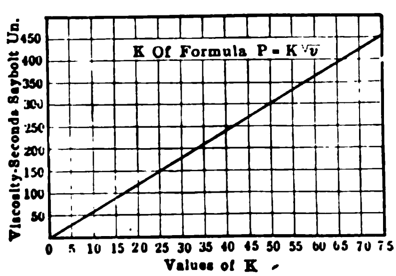


Fig. 14.—The relation between viscosity and K, the factor which modifies the relations between critical pressures and velocities.

K being a factor expressing the influence of viscosity, bearing fit, smoothness and grooving. In Fig. 14, which gives the relation between K and viscosity, it has been assumed that for ordinary journal-bearings which have been worn in, viscosity is the dominating factor.[1]

M. D. Hershey has shown mathematically that for low speeds the relationship is direct while for high speeds it closely approaches the cube root relation.

[1] See, also, H. F. Moore, Experiments, Formulas and Constants of Lubrication of Bearings: Am. Mach., pp. 1350–53, 1903.

For the purpose of selection of lubricants for the majority of journal bearings it will be quite satisfactory to assume that the breakdown pressure increases with the

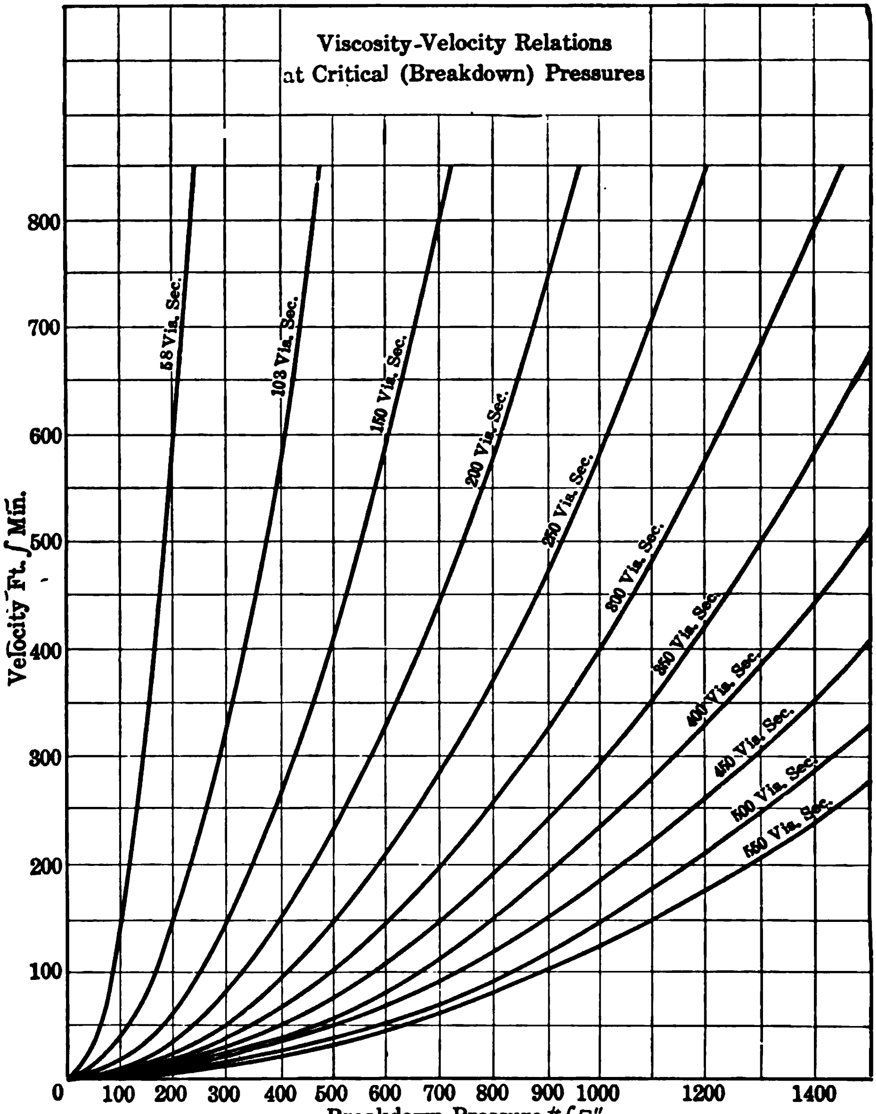


FIG. 15.—Viscosities applicable to a specific gravity of 0.91. Corrected viscosities obtained by multiplying viscosity, as read from curves, by (0.91 ÷ actual specific gravity of oil).

square root of the speed. The curve, Fig. 15, has been built up upon the basis of $P = K\sqrt{v}$, in which P is the breakdown pressure, K a constant, for a given viscosity, but varying with viscosity as shown in Fig. 14.[1]

[1] See also M. D. Hershey, Jour. Wash. Acad. Sc., Vol. IV, p. 549, 1914.

Effect of speed on thickness of oil film.—Professor W. F. Pullen,[1] found that film thickness is proportional to the surface speed.

$Y=j+hV$, in which Y = film thickness in feet, and j and h are constants.

Oil	Speed V	j	h
Heavy engine	between 1′ and 6.3′ per sec.	0.000038	0.00001283
	between 6.3′ and 8.5′ per sec.	0.0000605	0.00000927
Ordinary engine	between 1′ and 5.5′ per sec.	0.000031	0.0000100
	between 5.5′ and 9.0′ per sec.	0.0000445	0.0000075

Thickness of oil films varied from 0.0013 to 0.0029, increasing with speed.[2]

Albert Kingsbury found film thickness to vary from 0.0021 to 0.0023 for pressures from 27 pounds per square inch to 270 pounds per square inch.[3]

Effect of capillarity.—The wetting fluid exerts considerable force to fill continuously the narrowest places (area of closest approach of journal and bearing) and so prevents contact of the rubbing surfaces.[4]

Fundamental Requisites

The purposes of lubrication are (*a*) to protect the sliding surfaces from abrasion; (*b*) to attain the maximum economy of operation consistent with ample protection by minimizing friction. It is expected that the bearings are properly designed to prevent deformation by pressure.

The first consideration in the selection of a lubricant arises from the question, " What viscosity of lubricant will be needed to keep the bearing surfaces apart (since this is the primary object of lubrication) for the particular ' feed ' (supply of lubricant to make up for that expelled from the bearing) possible under the system at hand."

Every other consideration hangs on the answer to this question.

The problem is complicated by the fact that the viscosity which will successfully carry a bearing varies, not only with the load on the bearing but with the speed of rotation and possibly on the oil groove arrangement which enables the oil to be pumped by the journal to the point of maximum pressure in the bearing. (See " Method of supplying lubricant to the bearing.") Furthermore, the object sought is not only protection for the bearing by complete separation of the metallic surfaces, but also the minimum of frictional loss, which increases with the viscosity.

Moreover, high frictional loads may arise not only from excessive viscosity of lubricant, but also from abrasion permitted by imperfections in the oil film, arising from insufficient viscosity. In all events it takes much greater forces to shear (abrade) the metal surfaces of bearing and journal, if the abrasion is appreciable, than to overcome the resistance due to a reasonably selected viscosity. It is, however, quite possible to have *higher* frictional resistance and greater power loss with a lubricant of high viscosity, *without* abrasion, than with a fluid lubricant *with* abrasion, if the lubricant is *nearly* viscous enough to carry the film without breakdown, except at the lower speeds, and if the wear is occasional and superficial. (See also Note 1, page 629.)

[1] Mech. Eng., Oct. 15, 1909.

[2] Tests of J. Goodman, Proc. Inst. C. E., Vol. 85, Part III, pp. 376–92, 1885–1886.

[3] Trans. A. S. M. E., Vol. 24, pp. 143–60, 1903.

[4] L. Ubbelohde, Zur Theorie der Reibung Geschmierter Maschinenteile: Petroleum 7: 773.

To illustrate: The critical (breakdown) viscosity to carry the load of 120 pounds per square inch on the main bearing of a steam engine whose normal speed is 150 R.P.M. is 60 Saybolt Universal. The usual factor of safety has been disregarded and an oil of 80 viscosity at the (highest) working temperature has been selected and applied. At the start the film does not hold up fast enough to prevent some abrasion before the speed has reached a point making for a protecting film. (See Fig. 15.) When the engine is stopped the film breaks down as the speed approaches zero. At "start" and "stop" the friction is excessive and irregular, some abrasion occurs (this can be shown by analysis of the used oil)—but only for a few moments. During the hours of running, the frictional loss of the bearing was practically a minimum, say 0.2 H.P.

Now suppose a factor of safety of 5, far beyond the needs of the case, had been employed. The lubricant would have a viscosity of approximately 300 Saybolt. The power loss would be approximately 0.6 H.P. continuing every moment of operation of the machine. We can have too much protection for economy's sake. On the other hand it is possible to have, in bearings of great clearance, lower frictional value with higher viscosities even though the lower viscosities are above the critical point and carry a reasonable factor of safety.

The solution of the problem of selecting suitable viscosity for bearing lubrication resolves itself into this: Find the minimum viscosity requisite to support the load at the normal speed of operation under the condition of feed for the particular case, then apply a factor of safety which will strike a good balance between any "abrasion at starting and stopping" of the machine and the "loss occurring continually from the use of a viscosity giving too wide a margin of safety."

The starting condition is more rigorous than the stopping one, because time has usually permitted a more complete oozing of the lubricant, from between the metal surfaces, under dead load, but to apply the rule of "higher viscosity for lower velocity" to fit the starting speeds (fixed load), especially for machines of high normal speed, would be most wasteful of power. It is necessary, therefore, to be guided by experience in the selection of factors of safety; this has been done by drawing upon numerous cases in which operation has been successfully carried on for long periods without any noticeable wear or serious heating of the bearings, both conditions pointing to extremes of viscosity.

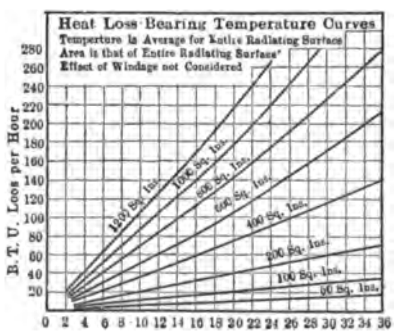


FIG. 16.—Theoretical bearing heat-losses

Factors of safety for flood feed (i.e., a quantity of lubricant somewhat in excess of the quantity needed to replace that expelled from the bearing by the action of the load) based on satisfactory and proved operation are given in Fig. 16. It will be noted that the factor of safety varies with the kind of work done and particularly with the range of velocities, and with the method and quantity of feed. The paramount requisite is a viscosity sufficient for reasonable protection at "start" and "stop" of the machine; otherwise the minimum of viscosity. A factor of safety has significance only when the supply of lubricant is ample to replace that forced from the bearing by the load.

It is evident that when a factor of safety is applied to care for the start and stop conditions the viscosity will be more than ample to give full protection under the working speed, provided the supply of oil is without interruption.

Bearings should be flooded with oil before starting, and copiously supplied on shutting down. Such a procedure permits of a lower factor of safety, and therefore economy of power.

Regardless of the desire to secure immense safety to bearings and regardless also of power loss, there are practical limitations to the factor of safety to be employed in any case. For example, an oil as viscous as cylinder oil, say 3000 seconds Saybolt Universal at 100° F., will not feed uniformly and continuously through some types of lubricators; again, the low demulsibility and high foaming qualities of an exceedingly viscous oil render it unsuitable for the lubrication of a turbine in a force-feed circulating system. *The factors of safety in practice to-day are commonly too high, especially for bearings supplied copiously with lubricant.*

The possibility that the supply of lubricant may be cut off, particularly to high-speed journal-bearings, should be provided for by "tell-tale" mechanical appliances which shut down the machine at once on cessation of flow of lubricant, and not by providing a lubricant of great body to protect the bearings (the oil film quickly becoming dangerously thin) until the stoppage of the oil flow is discovered.

According to F. E. Cardullo,[1] commercial lubricating oils will support pressures of 500 to 1000 pounds to the square inch before rupture. Two-thirds of these maximum pressures are allowable. Cardullo gives the formula:

$$p = PK \div (DN + K)$$

in which p = approximate unit pressure without seizure;
D = diameter of bearing in inches;
N = revolutions per minute;
P = the maximum safe unit pressure for the given circumstances at slow speed, e.g., 200 for collar-thrust bearings; 400 for shaft bearings; 800 for car journals; 1200 for crank-pins; 1600 for wrist-pins;
K = is a factor depending on the method of oiling and the care of the journal;
K = 700 for drop-feed lubrication, ordinary care;
1000 for drop-feed lubrication, excellent care;
1200-1500 for ring-oiling and force-feed;
2000 for air-cooling and perfect lubrication.

For crossheads, Cardullo gives:

$$p = PK \div (240\ V + K),$$

in which V = velocity of rubbing in feet per second.

All other conditions being constant, a car journal will carry twice the pressure of a flywheel journal—due to the fact that in the former case, irregularities in the road cause frequent separations of the journal and bearing with simultaneous renewals of the oil film. When rotation is over a limited arc, as with wrist-pins, or the point of application of the resultant bearing pressure varies, as in the case of crank-pins, conditions making for the renewal of the oil film are most favorable; such bearings will carry with safety three to four times the maximum pressures carried by a bearing continuously loaded.

It is suggested that the correctness of the viscosities of oils in use be checked against the factors of safety given on page 649. It is desirable that operating engineers know that the journals of their machines run safely and economically.

[1] Machinery, February, 1907.

If there is a suspicion that the factor of safety in a particular case is insufficient—a condition which may be true for a bearing having a rough wavy surface, occasioning excessive local pressures,—it is advisable to make a careful examination of the used oil for the presence of bearing metal.

Importance of Sufficent Oil Supply

A journal-bearing may be considered as a tube nearly filled with a plunger, the space between being filled with the lubricant. The load acting on the plunger tends to expel the oil; the capillary and viscous properties of the oil resist the expulsion of the liquid, the latter property acting over the entire area of the bearing; the space between the closely adjacent surfaces of the journal and bearing, and, to a slight degree, the open ends (orifice) of the bearing, offer opportunity for exercising the capillary (surface tension) characteristic. Capillarity decreases as clearance increases. Conversely as the journal approaches the bearing the force of capillarity tends to force the oil into the narrowest spaces. With cessation of " feed " both properties succeed in keeping the surfaces of the journal and bearing moist for a time; but the bulk of the lubricant is expelled by the dominating factor, " load "; the film thickness is dangerously reduced and friction losses extravagantly increased. Obviously, too, the greater the clearance, the more rapid the expulsion of oil. It is considered good practice to give the main bearings of steam engines a clearance of 0.005 inch for bearings 6 to 12 inches in diameter, and 0.004 inch for crank- and wrist-pins up to 6 inches.

For electrical machinery, clearances for horizontal bearings are given 0.002 inch for ½ inch journals; add to 0.002 inch, 0.001 inch for each inch of journal diameter up to 5 inches; 0.009 inch total clearance for 6-inch journal; add to 0.004 inch, 0.001 inch for each inch of diameter, for diameters from 7 inches to 16 inches; and from 16 inches to 24 inches diameter a clearance of 0.02 inch is given.

Lasche found that friction decreased with increase of clearance up to 0.06 inch and thereafter remained constant. His experimental bearing had a diameter of 10 inches.

The curves shown in Fig. 11 illustrate the fact that a definite feed is required to maintain a film of maximum thickness; that a feed above the minimum required for a complete film gives no frictional advantage; flood feed, of course, gives greater safety and by its cooling action permits the use of a lower initial viscosity. Fig. 11 also shows that for a given set of conditions, the higher the viscosity the less rapid the expulsion of oil from the bearing; and, of course, the greater the frictional loss.

Method of determining the minimum feed of oil to a journal-bearing required for safety and minimum power loss.—Apply the oil selected for use, copiously, but in measured quantity. Determine the bearing temperature rise for the condition of equilibrium by means of a thermometer inserted into a hole drilled in the bearing close to the rubbing surface; take simultaneous readings of bearing and atmospheric temperatures until a constant difference is noted. Decrease the feed and repeat. Continue the reduction in feed until a slight increase in the temperature difference of the bearing above room temperature is noted. The minimum required feed is between the two feeds last used in the test. It will be obvious to experimenters that conclusions should only be drawn when all conditions, except the variables under examination, are the same or are brought to the same basis of comparison.

Bearing temperatures and power losses.—It almost goes without saying that a bearing not artificially cooled will become warmer than the surrounding atmosphere. In most cases of machine operation this temperature rise is due entirely to friction

within the bearing, from metallic contact, from the fluid resistance of the lubricant or from both causes. The heat so generated is the direct equivalent of the power loss, following the laws of the mechanical equivalent of heat. See Figs. 16 and 17.

Unfortunately, perhaps, most machines are so constructed that all the heat generated cannot be measured. For a test bearing it is possible to approximate the total heat generated by measuring the heat radiated from a given area (say of bearing surface whose temperature can be measured accurately) which has been calibrated against the total heat calculated from the power loss, determined dynamically.

It happens that for certain of the more important types of machines, notably steam turbines and engines, some internal-combustion engines and electrical machinery, heat of external origin is conducted *to* the bearings through the machine frame or shafts. This external heat taken into a bearing makes difficult the application of knowledge of the temperature of a bearing in studying the quality of lubrication.

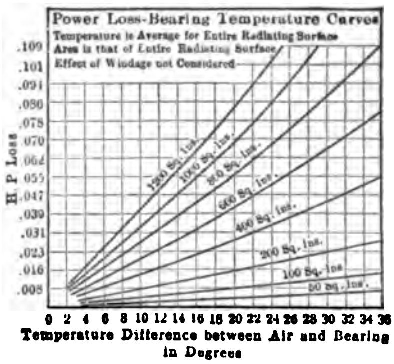


FIG. 17.—Theoretical bearing power-losses.

Theoretically, every bearing has a temperature equilibrium which indicates an ideal condition of operation. And unless the bearing is heated externally this temperature rise should be so slight as to necessitate no artificial cooling, either by water, air or excess of lubricant. Obviously with this premise, a hot bearing is an alarming sign, but as pointed out above, a hot bearing, to warrant anxiety, must be hot from friction.

Excessively high bearing temperatures are serious because of the effect of temperature in very rapidly reducing the viscosity of the oil and therefore decreasing the protection to the bearing. It is also common experience that as temperature increases and abrasion begins, the temperature increases more and more rapidly and abrasion proceeds very fast. Moreover, the fire hazard must not be overlooked.

Because in the past the systems of application of lubricants were inadequate and the selection of lubricants haphazard, the fear of abrasion caused designers to make journal-bearings as large as possible to give very low bearing pressures and large areas for the radiation of heat. The result has been excessive power losses, the frictional force increasing directly with the bearing area, other things being equal. These large bearings have permitted the use of low viscosities; but sufficiently low viscosities have not generally been used, especially in modern high-speed machinery using flood-feed lubrication, because the ability of the oils to support heavy pressures has not been appreciated or accepted.

The influence of bearing area on friction is shown in Fig. 10.

Bearing Unit Pressures

(Approximate; collected from various sources)

Type of bearing	Class of machine	Pressure, Pounds per square inch	Remarks
Main bearings	Corliss engines and other slow-speed engines	80 to 140	
Crank-pins		800 to 9400	Maximum for steam load
Wrist-pins		1500	
Slide blocks		25 to 125	
Slide blocks		30 to 60	
Main bearings	High-speed steam engines	50 to 150	Cases below 50
Crank-pins, overhung		900 to 1500	Maximum for steam load
Crank-pins, center		400 to 600	Maximum for steam load
Wrist-pins		1800	Maximum for steam load
Main bearings	Marine engines	275 to 400	600 maximum for slow engines
Crank-pins		400 to 500	
Wrist-pins			
Slide blocks		100	
Main bearings	Marine turbines	85 maximum	Horizontal
Main bearings	Stationary turbines	60	Horizontal
Main bearings	Hydraulic turbines	30	Horizontal
Step bearings	Vertical turbines	200 to 1000	400–450 average
Car journals	Railroad passenger car	300 to 400	Variable speed; occasional release of pressure
Car journals	Railroad freight car		
Locomotive driving journals	Passenger	190	
Locomotive driving journals	Freight	200	
Locomotive driving journals	Switching	220	
Locomotive crank-pins		1500 to 1700	
Locomotive wrist-pins		3000 to 4000	
Propeller thrust bearings		50 to 70	
Pivots of drawbridges		7000 to 9000	Slow; incomplete revolution
Crank-pin, shearing and punching machine		3000	Maximum momentary
Main bearings	Gas engines	500 to 700	Maximum with engine loaded
Crank-pins		1500 to 1800	do
Wrist-pins		1500 to 2000	
Motor bearings	Electric	30 to 80	Occasional high pressure due to excessive belt tension
Dynamo bearings			
Bearings line shafts, heavy		100 to 150	
Bearings line shafts, light		15 to 25	
Main bearings	Air compressors	122 to 220	
Crank-pins	Belt-driven, 100 pounds of air	244 to 402	
Wrist-pins		400 to 785	
Main bearings	Air compressors	160 to 237	
Crank-pins	Steam-driven, 100 pounds of air	565 to 700	
Wrist-pins		628 to 820	

Figures from the table should be employed only for making rough approximations of required viscosities. Bearing pressures are best obtained from the manufacturer of the equipment. Lacking data from the maker, graphic methods are suggested for the determination of bearing pressures.

NON-MECHANICAL CONDITIONS INFLUENCING SELECTION

The need for specifications supplementing the "viscosity" specification will appear in the following examples:

Case I.—The writer has lubricated a journal-bearing without abrasion and at a low coefficient of friction with a viscous solution of water and cane sugar. As the operation continued, however, the water evaporated, the viscosity of the lubricant increased, the friction increased, and finally the bearing ran altogether dry; the water having completely evaporated, the sugar was left as a coating of crystalline solids over the journal and bearing.

Case II.—Glycerin was similarly employed as a lubricant and economically supported the load on the bearing for certain velocities—but with variable and decreasing friction. Glycerin absorbs moisture from the air, which decreases its viscosity. Obviously, permanent changes of viscosity are undesirable; a decreasing viscosity jeopardizes the bearing; an increasing viscosity unduly raises the friction load, and may ultimately prevent the feeding of sufficient lubricant to the bearing. (The experiments described were made in an effort to determine whether the property of surface tension really affected the coefficient of friction or made for greater load-carrying capacity for a given viscosity.)

Case III.—Concentrated sulphuric acid has been used as a lubricant. Its viscous property enables it to meet the mechanical requirements of bearings for certain combinations of pressure and velocity. But sulphuric acid absorbs moisture, which reduces its viscosity. Further, it is corrosive and attacks the metal of machinery, foundations, wood floors, and the skin and clothing of persons on whom it falls.

Requirements Other than Viscosity

1. Stability or permanence of properties;
2. Passivity or harmlessness;
3. Mobility at low temperatures;
4. Minimum volatility at high temperatures;
5. Minimum affinity for other substances, e.g., low emulsifying qualities;
6. Miscellaneous requirements.

It will be evident that many conditions of lubrication do not demand that the lubricant meet all the specifications that can be formulated; for example, many cases do not require that the lubricant pass a demulsibility specification. Obviously, the fewer and simpler the specifications the better.

Determination of the possession of the desirable properties by the lubricant is made by ordinary laboratory testing methods. In what follows, mention will be made of tests suitable for such determinations, and reasonable minimum or maximum requirements will be given. It is costly, and sometimes ridiculous, to propose specifications more elaborate than the conditions of operation require.

1. **Stability or permanence of properties** of the lubricant is essential to the successful operation of all systems of lubrication in which the lubricant is used for a long and indefinite time. The significance of "stability" decreases as the time-use of the lubricant decreases. Permanence of properties requires that the essential qualities of the lubricant, viscosity, mobility at low temperature, harmlessness, ability to demulsify quickly, etc., shall not change appreciably during the time the lubricant is in service. This is indeed a general and paramount requirement, which is discussed below in more detail. Generally, the specification that the lubricant be a pure mineral oil (for bearings) of proper flash test (see section on volatility), will suffice to insure

the stability necessary to satisfy the condition of "short-time" use, as for example, in many drop-feed systems of lubrication unaccompanied by any recovery system.

For conditions demanding a non-emulsifying lubricant, the combination of demulsibility and flash tests will ordinarily serve as an adequate check to give the maximum of "permanence" necessary.

Stability of the lubricant, then, within the limits demanded by any particular set of conditions, becomes a requisite of the same order of importance as correct initial viscosity. It is of little avail to *determine* carefully a safe and economical viscosity, if the lubricant finally selected changes in viscosity (at a given temperature) during the period of use.

2. **Harmlessness or passivity,** signifying the inability of the lubricant to do permanent or irremediable harm to bearing metals, containers, clothing, skin, etc., is a requirement of prime importance. However, it is met almost universally by manufacturers of lubricating oils without the necessity of a specification. The corrosive propensities of a lubricant are quickly discernible; therefore, reputable manufacturers see to it that finished oils are free of corrosive constituents, or that such constituents remain in the oil to a negligible degree.

It is unnecessary to propose a detailed specification or a test to insure "passivity," other than the general statement that the lubricant shall not have a harmful action on the metals of bearings, or on other substances with which it may normally come in contact.

3. **Mobility** at the lowest working temperature is a required quality, equal in importance to viscosity, stability and passivity, because continuity of lubrication and therefore, of protection to bearings and economy of operation depend upon this property.

Some lubricants become solid (or, at least, reach a very high viscosity) at comparatively high atmospheric temperatures. Unless great care is exercised to see that lubricating devices and feed tubes holding such lubricants and conducting them to the friction surfaces are heated to temperatures above these critical temperatures, the supply of lubricant to the bearing ceases, or becomes insufficient, and high friction and all of its evil consequences follow. As a specific example: Petrolatum is quite fluid at temperatures above its melting point; if kept molten it makes a good lubricant for medium to high-speed bearings operating at low or medium pressures. In such a state it easily feeds through ordinary oil ducts. If the temperature drops below its melting point (say 120° F.) it freezes in the oil passages; lubrication presently ceases except for that continued by the durability of the film of semi-solid petrolatum left in the bearing.

Mobility is satisfactorily determined by the "cloud test" for transparent oils and the "pour test" for translucent and opaque oils. The cloud test should be at least 10° F. and the pour at least 15° F. below the lowest "working temperature" to satisfy the requirements for mobility. By "working temperature" is here meant the lowest temperature to which the oil is subjected in its passage from the feeding reservoir to the bearing. Occasionally it may be necessary to specify a maximum viscosity at the "working temperature" instead of "cloud" or "pour" test, because excessive viscosity may prevent the feeding of a sufficient quantity of lubricant.

The specification suggested above has particular application to, and is generally necessary only for oils working at temperatures under 60° F. However, even for working temperatures above 60° F. it is quite proper to apply oils having cloud or pour tests below 40° F. Such oils should be easily obtainable without additional cost.

4. **Minimum volatility** is a requirement which is properly specified for the insurance of stability of the viscous property and as a measure providing against excessive loss of the lubricant in use by evaporation, and against fire.

High bearing temperatures necessitate attention to the volatility of the lubricant, a property which is measured with sufficient accuracy by the flash and fire tests. When possible, and with few exceptions it is always possible, the oil should have a flash point of at least 100° F. above the temperature of the bearing. Generally, oils testing above 300° F. flash are easily available.

Volatilization or evaporation, being essentially a process in which the more volatile and less viscous constituents of the oil pass off first, causes the lubricant to increase in viscosity; it creates a fire hazard because of the explosive nature of mixtures of air and oil vapor, and causes a haze in the atmosphere in which the oil evaporates. Ultimately, the vaporized oil condenses and deposits as a fine film on the machinery, surrounding objects, windows, etc. The same harmful effects or tendencies are produced by the mechanical atomization of oil which is subjected to violent agitation.

Chemical changes, particularly oxidation, proceed more rapidly at elevated temperatures; high temperatures therefore demand oils of superior stability.

It is noteworthy that all oils approach a minimum and practically constant viscosity at their fire test. Oils of low fire test lose viscosity rapidly with increased temperature.

5. **Ability to demulsify quickly and completely** is demanded of oils used in the lubrication of many steam turbines and in the enclosed crankcase type of steam engine. Water of condensation may, and often does, come in contact with the lubricating oil, and is churned with it, subjecting the oil to conditions conducive to emulsification. If the admixed water is free of demulsifying agents, e.g., fatty oils, and the oil will pass the "resistance to emulsification" test with a score of 50, or the Herschel demulsibility test with a score of 600 for oils of viscosity below 150 Saybolt at 100° F. (400 Herschel demulsibility for oils of 200 viscosity), and especially if the lubricating system provides suitably large and heated settling tanks, the oil will separate completely from the water before it returns to the bearings of the turbine or reciprocating engine.

Unfortunately, the water with which the oil is thrown in contact sometimes carries alkali which accompanies the steam on priming of the boilers; or compounded cylinder oil, which has been used for piston-cylinder lubrication. Such substances contaminate the lubricating oil, induce emulsification and make the complete separation of oil and water practically impossible.

Certain circulating lubricating systems for prime movers or process machinery are provided with settling or clarifying tanks in which advantage is taken of the clarifying effect produced by the passage of the oil upward through water. Obviously, oil employed in such a system must have good demulsifying or non-emulsifying qualities.

"The constituents of turbine oil (oil of good demulsifying quality) which cause it to become resinous or gummy in use are, in general, resin-like hydrocarbons containing oxygen and sulphur, of high density and refractive index. They are unsaturated terpene-like compounds and are easily absorbed by boneblack." [1]

6. **Miscellaneous requirements.**—There are numerous practical conditions in the operation of machinery which bear strongly on the selection of the lubricant. After the fundamental requirements of the bearing itself have been determined in terms of oil properties—such requirements fixing primarily the characteristics of "viscosity" at the working temperatures, "cold test" for feeding and "flash test" for fire hazard and loss—some incidental conditions may further require specific incorporation into the oil specification. In this chapter it is scarcely possible to do more than point out the existence of such conditions.

[1] From "Testing and Judging of Steam Turbine Oils," by F. Schwartz and J. Marcusson, Z. Angew Chem., 26: 385–9.

For example, the possibility of oil stains on certain fine textile fabrics, caused by the falling of oil from an overhead line shaft, may determine that no liquid lubricant shall be employed overhead. Again, the presence of steam about a bearing will influence not only the viscosity selected, but also the character of the oil with respect to emulsification. Clouds of abrasive powder about a bearing, getting into a bearing with the oil, may demand a flood (and flushing) feed of oil of low viscosity and the installation of a filtration system through which the oil will pass frequently. In a word, the problems of lubrication are eminently those of engineering and are to be solved on the basis of all the fundamental principles which can be brought to bear, tempered with abundance of observation of, and experience with, all associated conditions.

CONDITIONS INFLUENCING THE CHOICE OF FACTORS OF SAFETY FOR VISCOSITY

1. **The method and quantity of feed,** more often than any other condition, necessitates a modification of the viscosity selected to suit the mechanical conditions of the bearing. A lubricating device, or an "economical turn of mind," which limits the feed of oil to a point below that necessary to maintain the complete film (which would obtain if an ample feed of an oil of correct viscosity were supplied), of course, requires the selection of a lubricant that will be expelled very slowly from the bearing. In other words a higher viscosity must be used.

The problem of selection in the case of restricted feed is this: to find the point of balance between—(*a*) a determined feed; (*b*) some viscosity; (*c*) the minimum of hazard from abrasion; and (*d*) minimum of power loss. This condition is often met in machinery operation; it is the case of the semi-lubricated bearing, which, for the lack of a system of copious flow, collection, purification and return of the oil to the machine permits some abrasion and excessive friction.

In this, as in numerous other lubricating problems, practical experience is the only guide. Operating results, temperature-of-bearing tests, and power-loss tests prove the correctness of the selections. As a simple guide, we know that the flow of oil under gravitational or other forces is proportional to its viscosity. Therefore, in a plain bearing, fed by a sight-feed gravity lubricator, we may expect, roughly, to decrease the feed as we increase the viscosity; of course, the power loss increases with the viscosity. Here again, economy and not theoretical considerations, must control the selection—the problem is to find the balance between the cost of the lubricant (including the cost of application) and the cost of power losses.

Reference to the Feed-friction Curve, Fig. 11, will show that good lubrication can be obtained without flood feed and indeed with a very limited feed of high viscosity oil if the power loss is disregarded. Factors of safety, as used to modify the critical viscosities, must be made especially large for reduced speeds, as shown in the table on page 649, bearings consequently run hotter and consume more power when the feed is limited.

2. **Temperature changes.**—The working temperature of a bearing may change, even under the condition of good lubrication, because of change in the atmospheric temperature or change in the amount of heat conducted to the bearing from external sources. If these temperature changes are of small magnitude they carry with them little significance in influencing the selection of viscosity. If, however, the temperature changes are appreciable, one of two courses may be followed: the lubricant may be varied with the change in the temperature condition; or a viscosity

may be chosen suitable for the severest set of conditions, and this viscosity made to serve for all conditions. The operator must make his own choice.

The relation between viscosity and the flash test has been previously mentioned. The change of viscosity with temperature is less marked with hydrocarbons of the C_nH_{2n+2} series, than with the C_nH_{2n} compounds.[1]

The viscosities of a few of the more viscous hydrocarbons are given below as a guide to the relations between boiling points, gravities, viscosities and chemical constitution:[2]

Hydrocarbons	Boiling point	Specific gravity	Specific viscosity
$C_{10}H_{22}$	174–5	0.753	0.95 at 20° C.
$C_{12}H_{26}$	212–214	.769	1.49 at 20° C.
$C_{15}H_{32}$	158–159 (50 m.m.)	.793	2.79 at 20° C.
$C_{16}H_{34}$	174–175 (50 m.m.)	.799	3.35 at 20° C.
$C_{18}H_{38}$	199–200 (50 m.m.)	.813	5.97 at 20° C.
$C_n H_{2n+2}$	274–296 (50 m.m.)	.775	8.51 at 60° C.
$C_n H_{2n}$	274–296 (50 m.m.)	.835	15.63 at 60° C.
$C_n H_{2n+2}$	294–276 (50 m.m.)	.781	10.88 at 60° C.
$C_n H_{2n}$	294–276 (50 m.m.)	.841	21.23 at 60° C.

3. **Grouping the results of lubrication analyses.**—The most practical, but unfortunately also, the most abused, principle of the choice of lubricants is the one which dictates that, for the purpose of minimizing the cost and trouble of handling a large number of different lubricants and for preventing confusion in the application of lubricants, the results of the analyses of the mechanical requirements of machinery must be condensed so that a very limited variety of oils will be employed.

For example, the complete analysis of the equipment of a machine shop and its adjacent power plant may very logically point to the need for eight or ten bearing oils ranging in viscosity from 60 seconds to 500 seconds Saybolt. For convenience the requirements are collected into several groups, the highest viscosity needed for any particular equipment in any group being assigned to that group. By this means the variety of oils may be reduced to four or less.

It is obvious that the method of grouping viscosities results in higher power losses for all units of equipment which logically require a viscosity lower than that selected for the group. The factor of safety for the most severe condition in any group, which determines the viscosity of the lubricant used for that group, may be reduced cautiously. The most satisfactory arrangement is, however, to strike a balance between the costs of (*a*) handling and application; (*b*) power lost by the application of unnecessarily viscous oils in some places; and (*c*) excess cost of the more viscous lubricant. All of the conditions in any particular case must be brought together and a practical solution reached on the basis of the foregoing principles.

4. **Excessive bearing clearance** properly constitutes a good reason for modifying the viscosity of an oil selected to meet the pressure-velocity conditions for normal clearance.

Excessive clearance may be due to radical design, inferior workmanship, wear accompanying mistreatment of the bearing, or to bearing metal which is too soft to withstand the bearing loads without distortion.

[1] See also "Relations between Viscosity of Liquids and Their Chemical Natures," Thorpe and Rodgers, Philos. Trans., Royal Society, February 22, pp. 397–710, 1894.

[2] From C. F. Mabery and J. H. Mathews, Jour. Am. Chem. Soc., Vol. 30, pp. 992-1001, 1908.

In general, excessive bearing clearance permits the use of high viscosity without unduly raising the friction coefficient; in cases of bearing pressures of high magnitude and variable direction, excessive clearance demands the selection of viscosity above that normally to be selected. High speeds of rotation, particularly, on account of the tendency to concentricity of journal and bearing, make the use of higher viscosity practicable and desirable, when the clearance is excessive.

The conditions of any specific case must determine the amount of modification of the " normal " viscosity.

ANALYSIS OF TYPICAL UNITS FOR THE DETERMINATION OF BEARING OILS

The factors to be kept in mind are: (*a*) unit bearing pressure; (*b*) circumferential velocity of journal; (*c*) working temperature; (*d*) method and amount of application of lubricant; (*e*) bearing clearance; (*f*) special conditions, e.g., dust, moisture, two-fold function of lubricant, etc.

Case I.—Unit: 15 H.P. Westinghouse type C.C.L. induction motor, 220 volts, 60 cycles.

Bearing area—2 inches $\times$ 2 inches $\times$ 5 inches = 20 square inches.
Bearing pressure—Rotor weight 155 pounds; belt pull horizontal on one bearing, 256 pounds; resultant load 268 pounds = 26.8 pounds per square inch.
Speed—845 R.P.M. = 445 feet per minute.
Room temperature—75° F.
Method of feed—Ring-oilers.

The factor of safety is 3.65. The equivalent load is $26.8 \times 3.65 = 97.8$ pounds per square inch. The viscosity at the working temperature, say 80° F., is 28 for 97.8 pounds per square inch and 444 feet per minute, taken from Fig. 15. As a matter of fact, oils of 28 viscosity are not manufactured. Indeed this viscosity is below the viscosity of kerosene. But the viscosity of kerosene, if the lubricant of this viscosity is supplied copiously, is ample to support pressures of low magnitude at high speed.

According to common experience very great factors of safety are employed in the lubrication of such units, giving rise to the use of oils of upwards of 100 viscosity. Indeed the motor described was lubricated with an oil of almost 206 viscosity at 100° F. The bearing-temperature rise with this oil was 9° F.; an oil of 140 seconds viscosity on the same bearing gave a temperature rise of 6.3° F., and a power saving over the more viscous oil of 120 watts or approximately 6 per cent of the no-load input. The analysis indicates that a much more fluid oil could be used with safety.

Case II.—Unit: Marine turbine for high-speed ship.
Bearing area—27.5 inches $D \times 44.75$ inches, $L = 1230$ square inches.
Bearing pressure—98,400 pounds = 80 pounds per square inch.
Speed—187 R.P.M. = 1350 feet per minute.
Temperature—oil from bearing 130° F.
Lubrication—circulating force feed.

Factor of safety 4.2; equivalent load, $80 \times 4.2 = 336$ pounds per square inch. From the formula $P = K\sqrt{v}$, in which $P = 336$ pounds per square inch and $v = 1350$ feet per minute, $K = 9.14$. The corresponding viscosity, determined for the working temperature, from Fig. 14, is 60 seconds Saybolt Universal. By interpola-

tion (Fig. 8), the viscosity of the oil at 100° F., converted from the working temperature of 130° F., is 93 seconds.

Theoretically, the power loss in this bearing, lubricated with the oil selected (specific gravity = 0.865) above will be:

$$\frac{0.000,000,019\times\overline{27.5}^3\times 44.75\times\overline{187}^2\times .0865}{12}=4.43 \text{ horse-power},$$

assuming the clearance to be 0.024 inch.

Table of Factors of Safety

(Applicable to Fig. 15)

Speed, Feet per minute	Flood-feed	Ring-oilers	Sight-drop feed	
			Rapid and regular	Slow and interrupted
50	2.0	2.5	3.0	4.0
100	2.2	2.75	3.3	4.4–5.0
200	2.4	3.0	3.6	4.8–5.8
300	2.6	3.2	3.9	5.2–6.4
400	2.8	3.5	4.2	5.6–6.7
500	3.0	3.8	4.5	6.0–7.0
600	3.3	4.1	5.0	
800	3.6	4.5	5.4	
1000	4.0	5.0		
1500	4.3	5.4		
2000	4.6			
3000	5.0			
4000	5.3			
5000	5.5			
6000	5.7			

If greater safety were desired a factor of 8 might be used. The pertinent values would then be: equivalent pressure, 640 pounds per square inch; $K = 17.4$; viscosity at 130° F. = 113; viscosity at 100° F. = 230. The friction horse-power would, of course, be about twice as great as before—in the writer's opinion, without justification.

The oil selected should have a flash test of at least 250° F., preferably upwards of 300° F., the latter being easily obtainable. It should pass the R.E.[1] test with a reading of 50. A cloud test below the lowest room temperature, say 60° F., will suffice.

Case III.—Unit: Tandem compound rolling mill engine, 46 inches × 80 inches × 60 inches.

Bearing area—2 × 30 inches D × 52 inches, L = 3120 square inches.

Bearing pressure—Flywheel, 110,000 pounds, shaft, 55,000 pounds = 53 pounds per square inch dead load. Combined loads approximated at 96 pounds per square inch.

[1] Resistance to emulsification.

Speed—80 R.P.M. = 628 feet per minute.
Lubrication—automatic sight drop feeder.
Temperature—room 95° F.; bearing, approximately 130° F.

The safety factor is 5.1; equivalent load is $96 \times 5.1 = 490$ pounds per square inch. At 628 feet per minute (Fig. 15), the required viscosity at the working temperature is 118; the viscosity at 100° F. by interpolation from Fig. 8 is 235 seconds Saybolt Universal.

Case IV.—Unit: 150 K.W. rotary converter. The continuously high temperature of the bearing on the alternating-current side had given alarm and started investigation. The converter operates in a clean atmosphere at a room temperature of 105°–110° F.

Bearing area—4 inches $D \times 10$ inches, $L = 40$ square inches.
Bearing pressure—Assumed one-half of rotor weight of 5200 pounds = 65 pounds per square inch.
Speed—900 R.P.M. = 1047 feet per minute.
Temperature of bearing—140°–150° F.
Lubrication—One ring-oiler.

Factor of safety 5; equivalent pressure, $65 \times 5 = 325$ pounds per square inch. Value of K is $325 \div \sqrt{1047}$ equals 10; corresponding viscosity at the working temperature (Fig. 14), is 63.

The room temperature varies between 105° and 110° F., but the temperature of the hot bearing varies between 140° and 150° F. when lubricated with an oil of 280 seconds Saybolt at 100° F. (103 seconds at 145° F.) By interpolation (Fig. 8) the selected viscosity of 63 at 145° F. will be 150 Saybolt Universal at 100° F.

As a matter of fact, the elevated bearing temperature was due in large measure to electrical losses in the machine, transformed to heat which was conducted to the bearing on the alternating-current side. The difference between the converter frame temperature (taken in the hole tapped for the eye-bolt) and the bearing was 13° F., for the oil of 280 Saybolt Universal at 100° F., and was reduced to 6° F. when the bearing was lubricated with an oil of 140 Saybolt Universal at 100° F.

The oil selected should have a flash test of at least 250° F. and a cloud test of below 60° F. It should be an easy matter, however, to obtain a flash test of upwards of 300° F. and a cloud test below 40° F. It should pass the Waters oxidation test with a result below 2 per cent for the reason that operating continuously in the bearing for several months at an elevated temperature, it should be proof against gumming or appreciably thickening.

Because of the length of the bearing and the restriction in lubrication to one oil-ring, a factor of safety, up to 50 per cent above that given in the table, page 649 may be used advisedly.

POWER CYLINDER LUBRICATION

There are sufficient experimental data to justify the assumption that the laws of friction of lubricated surfaces apply to piston-cylinder friction quite as well as to journal-bearing friction. But our knowledge stops with the qualitative relationships; we are not in possession of the necessary constants to enable us to determine the exact quantitative relationships between the pertinent factors, e.g., between the load, the supporting power of the viscosity and the velocity of piston travel.

The difficulty is further increased by the variableness of the conditions, for even

in the same engine the temperature (and, therefore, the viscosity) will vary with the power load carried by the engine, with the cylinder-jacket temperatures, etc.

However, for the general range of piston loads and speeds, assuming for the moment that steam pressures and temperatures and cylinder-wall temperatures are constant, we are able to make selections of viscosity that follow the direction of the qualitative relationships of friction, pressure, and speed with a fair degree of probability. Furthermore, the temperature condition, which does vary considerably and greatly affects the decrease of viscosity from the ordinary, convenient testing temperatures of 100° F. or 210° F. to the working temperature, is a matter of fairly definite knowledge, so that with regard to this important condition we are able to make reasonably accurate selections of viscosity.

Steam Cylinder Lubrication

The importance of correct cylinder lubrication lies in the fact that more than 20 per cent of the total friction of a steam engine is developed in the cylinder and piston-rod stuffing box, and as much more power may be absorbed at the valve-faces.[1] Beyond question or doubt, the lubrication of the piston reduces very considerably the power lost by friction in the cylinder.[2] Cylinder lubrication further functions in preventing loss of steam by leakage past the rings and to some degree decreases the loss of heat by conduction through the cylinder walls.

1. Selection of cylinder oil.—The method of arriving at the basic properties of cylinder oil for a given set of conditions, as presented below, is very open to the criticism of being arbitrary, because the constants necessary for accurate variation of these basic properties have not been determined by systematic, deliberate experimentation. Scientifically, such a criticism is entirely justified; but it is believed that the figures and charts will be of real assistance to engineers, who may properly place confidence in them for the following reasons:

1. The methods presented have been checked by numerous cases of the successful lubrication of steam engine cylinders;
2. The variations in properties as given follow the results of qualitative experimentation;
3. The method involves such factors of safety as to permit, with safety, reasonable deviation from the exact figures arrived at;
4. The method is as accurate in its application to the selection of lubricants as the methods employed in the design of the machine parts involved.

It is to be appreciated that fairly liberal limits of variation of viscosity and compounding must be accepted at this time in the recommendation of specifications for steam-cylinder oils, as for example, 5 per cent to 10 per cent on viscosity (measured at 210° F.), and from nothing to 5 per cent on compounding. Analysis, to date, of the significance of the several factors entering into "selections" do not warrant closer approximations.

[1] Professor R. H. Thurston found the distribution of friction in steam engines to be as follows:

21-inch by 20-inch condensing engine.—Main journals, 46 per cent; piston and rod, cross head and pins, 21 per cent; valve-rod and eccentric, 21 per cent; air pump, 12 per cent.

7-inch by 10-inch 20 horse-power engine.—Main journals, 35.2 per cent; piston and rod, 16 per cent; piston rings, 6.5 per cent; crosshead, crank- and wrist-pins, 13.1 per cent; eccentric and links, 8.2 per cent; slide-valve and rod, no steam, 1.5 per cent; 40 pounds steam, 19.5 per cent.

12-inch by 18-inch 100 horse-power automatic.—Main journals, 41.6 per cent; valve and gear, including eccentric, 9.3 per cent; piston, crosshead, crank- and wrist-pins, 49.1 per cent.

[2] See T. C. Thomsen in "Engineer," April 9, 1909.

Conditions to be Considered in the Selection of Cylinder Oil

The factors controlling selection may be divided into four classes:

1. Those mechanical conditions affecting the determination of viscosity;
2. Those conditions determining the character of the oil, e.g., pure mineral or compounded oil;
3. Conditions tending to modify selections of viscosity and character, e.g., method of feed, quality of steam, usage of exhaust, etc.;
4. Conditions determining the chemical character of the lubricant.

1. **Mechanical conditions in the cylinder comprise essentially:**—(*a*) The weight of the piston (horizontal machines); or piston thrust on the cylinder:

(*b*) The diameter of the cylinder and length of the piston:

(*c*) The velocity of the piston travel:

(*d*) The temperature of the steam and cylinder walls.

The form, number, width and tension (approximately 2 pounds per inch of circumference) of the piston rings; quality and condition of the cylinder and piston surfaces, and alignment of the piston with the cylinder undoubtedly have a strong influence on the operation of the piston in the cylinder; but ordinarily, for obvious reasons, they can have little influence on the selection of the lubricant. They often assert themselves by preventing satisfactory operation of the piston, with the possible sequel of condemnation of a good and well-selected lubricant. Change of lubricant is not the remedy for glaring mechanical defects.

The weight of the piston is an important element in determining the unit pressure on the cylinders of horizontal engines, particularly those of the crosshead type. Pistons are commonly made hollow to permit superior construction (in the trunk type), to decrease inertia effects, to lessen the cost, and, most important from a lubrication standpoint, to minimize the friction load. Piston loads are, of course, exerted only against the lower surface of the cylinder of horizontal engines, for the most part extending from the lowest longitudinal line of the cylinder surface up the side in both directions for a distance of about one-tenth of the circumference—the pressure varying from maximum at the lowest point to zero at the highest point.

In vertical engines of the crosshead type, and in horizontal engines with tail rods, carried on crossheads, the weight of the piston has little influence on cylinder friction, although it plays a more or less important part in the frictional values at the wrist-pins and connected portions of the mechanism of vertical engines.

The diameter of the cylinder and the length of the piston give the bearing surface of the piston, which is essential to the determination of the unit load to be supported by the lubricant (for a piston without a tail rod), and inform us of the total area of oil film, the resistance of which must be overcome as the piston is pushed from end to end of the cylinder.

The unit load on the cylinder is determined by dividing the weight of the piston plus half the weight of the rod by the area of contact, determined by the formula:

0.65 cylinder diameter × length of piston in contact with the cylinder (including piston rings).

The weights of the piston and rod are best obtained from the engine maker; the load on the cylinder may be approximated by the formula:

$$W = \frac{66{,}500 D^2}{L N^2},$$

in which W = piston load in pounds;
D = diameter of cylinder in inches;
L = stroke in feet;
N = revolutions per minute.

The length of the piston may be approximated by the formula:

$$L.P. = 0.46D, \text{ for high-speed engines,}$$

and $L.P. = 0.32D$, for low-speed engines of the Corliss type;
D = cylinder diameter in inches;
$L.P.$ = length of piston in inches.

The velocity of piston travel in feet per minute, as measured by the product of the length of stroke and the number of strokes per minute, has a decided influence on the character and rate of feed of the lubricant for non-abrasive and economical lubrication. Piston speeds vary greatly: for steam engines, speeds below 100 feet per minute are found, while for the modern high-speed engine the piston may travel up to 1200 feet per minute. The principle of " low viscosities for high speeds " applies equally as well to cylinders as to rotating bearings. The friction coefficient may indeed be less for an oil of lower viscosity when the oil is fed in sufficient quantities to maintain a perfect film and the load is not great enough to break this film.

Whereas the frictional losses at lubricated surfaces increase directly with the velocity, other conditions remaining constant, higher velocities at times assist materially in building up a film of lubricant of appreciable (or even maximum) thickness. The effect of velocity on breakdown load has been discussed. Velocity functions similarly in the lubrication of reciprocating parts. The viscosity-pressure-velocity relations applicable to the selection of lubricants for bearings probably hold for cylinder lubrication tempered, of course, by the fact that piston speed drops to zero twice each revolution. Provided the ends of the pistons and edges of the piston rings are properly chamfered, the greater velocities function to build up pressure under the piston and rings on reversal of the strokes so that a satisfactory film separates the rubbing surfaces.[1]

The form of piston rings and their fit in the piston grooves have no doubt a material influence on the coefficient of friction, on the consumption of the lubricant and on the life of the rings and the cylinder. When operating properly the piston rings should tend to build up a film of lubricant between themselves and the cylinder walls. For this purpose their outer edge should be slightly rounded—somewhat like the front end of the runner of a sleigh—so that the ring may ride over the oil film rather than plow through it. Should the edges of the rings be left square, it is evident that oil will be pushed before the ring, accumulate in a pocket at the end of the stroke and pass out with the exhaust, unused. The rings, furthermore, should have an easy, free, floating fit in their grooves. A tight ring not only functions poorly but is a positive danger. Tight rings, whether poorly fitted or clogged in place by some foreign substance, tend to increase greatly the friction coefficient and often badly score the cylinders. It is impossible, indeed, to lubricate satisfactorily a piston with poorly fitted rings. No quantity of any lubricant, regardless of chemical stability, high viscosity and sufficient compounding, will prevent contact between the cylinder and the sharp edges of misadjusted rings. Misalignment of the piston and cylinder will cause the same trouble.

The temperatures of the cylinder walls and steam temperatures constitute an important element of consideration in the selection of adequate viscosity because the viscosity at the working temperatures determines both the factor of safety of load-carrying capacity and the film friction, and the viscosity at the working temperature may be very different from the viscosity of the oil at the standard (and only convenient) testing temperature of 210° F.

[1] Professor Osborne Reynolds found that continuous lubrication and reciprocating motion are not incompatible if the surfaces be curved.

It is to be recognized that for conditions of good lubrication the effect of frictional heat on the reduction of viscosity is small compared to the effect of heat from the steam.

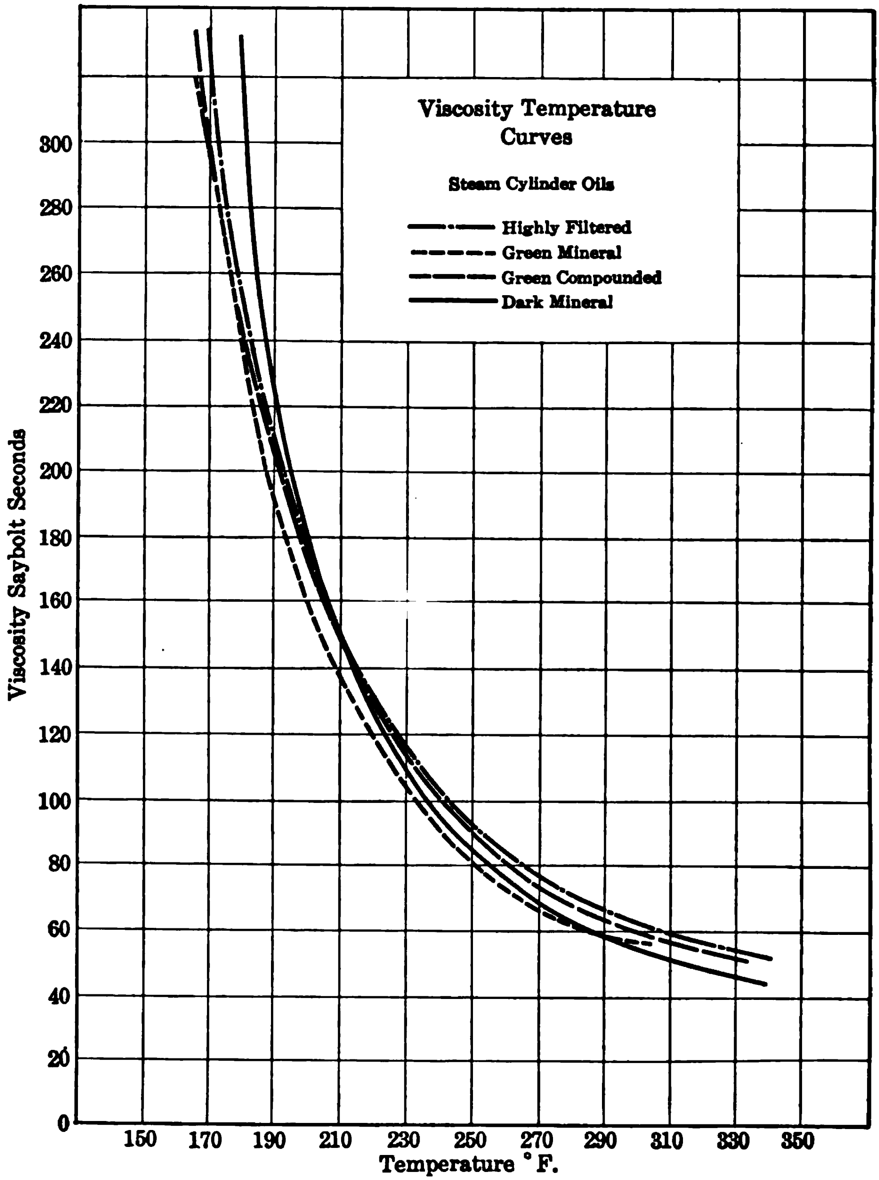


Fig. 18.—Change of viscosity with temperature. Cylinder oils.

The viscosity-temperature relation for several commercial cylinder oils, compounded and pure mineral, is shown in Fig. 18.

The *rate* of decrease of viscosity with increasing temperature, from 210° F.,

is important and should not be materially in excess of that given in the curves. No special emphasis is laid on this point in the oil specifications to be made hereafter for the reason that if the oils meet the necessary requirements of *a*, " pure or slightly compounded (see below) petroleum oils " and *b*, the precipitation " asphaltum " test, their change of viscosity with temperature will approximate that of the oils given. Note that the rate of change of viscosity increases with the initial viscosity.

Obviously, for purposes of specification, the viscosity determined at the working temperature must be converted into viscosity at the standard temperature. Should the steam pressure, or degree of superheat of steam supplied to a given engine, be changed materially, it is equally obvious that a proportional change must be made in the viscosity of the oil in order to continue safe and economical lubrication.

Figs. 19 and 20 supply the method of determining the viscosity of oil requisite for a given set of conditions inside the cylinder. Any necessary modifications of this determination will be discussed in the following sections:

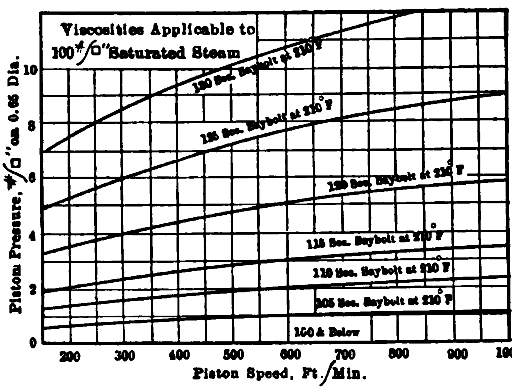


FIG. 19.—Variations of viscosity of cylinder oil with piston pressures and velocities.

How to use the charts. **Case** 1.—The dead load on the lowest 0.65 of circumference of a high-speed automatic engine is 2.96 pounds per square inch. The piston speed is 600 feet per minute; the initial steam pressure, 100 pounds per square inch.

The viscosity curve passing through 2.96 pounds per square inch (taken as 3) and 600 feet per minute, is 115 seconds Saybolt at 210° F. for 100 pounds of steam.

Case 2. **Conditions.**—Corliss engine 30 inches by 60 inches making 65 R.P.M. The piston load is 10.7 pounds per square inch; piston speed 650 feet per minute; initial steam pressure, 150 pounds per square inch.

The curve passing through 10.7 pounds per square inch piston pressure and 650 feet per minute piston speed, is, by interpolation, the curve for 129 viscosity at 210° F. and 100 pounds of steam. To correct to 150 pounds of steam, refer to Fig. 20. Note the intersection of the coordinates for 129 viscosity and 100 pounds per square inch steam; from this point, follow upward, parallel to the adjacent curve, to the 150 pounds per square inch steam line. The viscosity corrected from 100 pounds to 150 pounds steam is found on the viscosity base line immediately below this point, 156 seconds Saybolt at 210° F.

Case 3.—A vertical engine operates at a piston speed of 550 feet per minute; 175 pounds per square inch steam, carrying at 150° F. superheat.

Pressure due to piston weight *nil*; from Fig. 19, by interpolation, a viscosity of 95 at 210° F., applicable to 100 pounds of steam is taken. (Allowance made for piston-ring tension.) Converting, by Fig. 20, to 175 pounds per square inch as before, gives 138 viscosity. Correcting for 150° F. superheat, by adding one second of viscosity for each 4° superheat, $138 + \frac{150}{4} = 176$ seconds Saybolt at 210° F.

The need for careful selection of viscosity.—There are some who insist that lubrication of steam cylinders using moist steam is unnecessary. Their argument is based on the fact that the lubricant decreases friction only by a negligible amount. If the

lubricant is excessively viscous, especially when the unit piston load is low, this argument is logical. The large film area, if lubrication is used, demands careful selection of the lubricant to avoid power loss caused by fluid friction. Even slight differences in viscosity will be evident if the effect is followed over a period of time. But it must not be overlooked that the hazard of abrasion is too great to make it advisable to operate without lubrication.

The following examples will make clear the relative friction losses, with and without lubrication. It is appreciated that the ideal conditions assumed for the examples are probably met but seldom in practice.

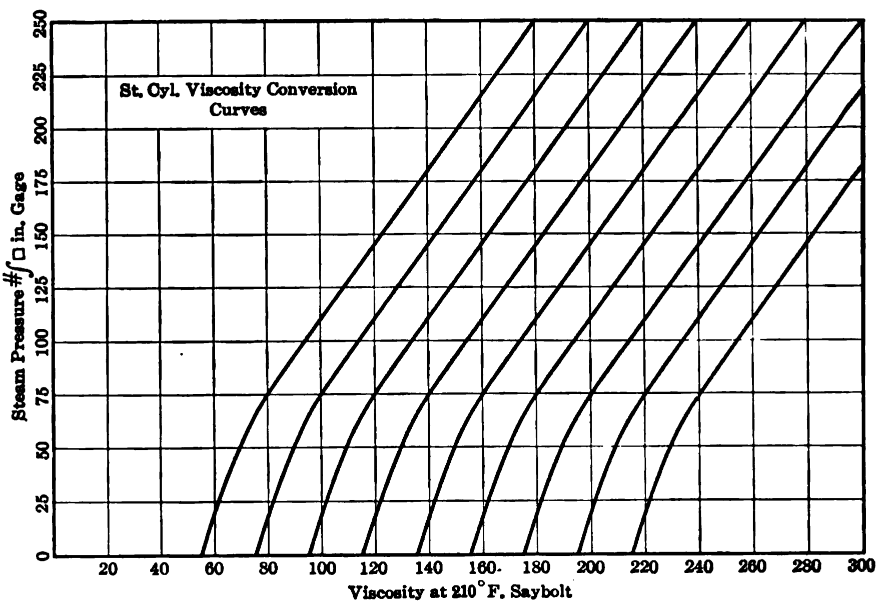


FIG. 20.—For the conversion of viscosities of cylinder oils, determined for steam of 100 pounds to the square inch pressure, viscosities applicable to other pressures.

The frictional resistance offered to the motion of the piston by the oil film may be determined from the formula:

$$F=\frac{0.00291\times(\pi)D\times L\times 2N\times S\times U}{}$$

in which F = pounds;

D = the diameter of the cylinder in inches;

L = length of piston (including rings) bearing on the cylinder;

N = revolutions per minute;

S = stroke in feet;

U = absolute viscosity of the oil at the working temperature;

t = average thickness of oil film in thousandths of an inch, for practical computations approximating half of the difference between cylinder and piston diameters.

Example. Assuming $D=20$ inches; $L=8$ inches; $S=3$ feet; $N=150$;
$U=.15$ (assumed 92 viscosity Saybolt Universal);
$t=6$ (assumed concentric; radial difference average 0.012 inch).

$$F=\frac{0.00291\times3.14\times20\times8\times2\times150\times3\times0.15}{6}=32 \text{ pounds.}$$

The frictional loss for these conditions will be found by the formula:

$$\text{Horse-power}=\frac{F\times2NS}{33{,}000}=\frac{32\times2\times150\times3}{33{,}000}=\frac{288}{330}=0.872 \text{ horse-power.}$$

For an unlubricated dry cylinder the frictional resistance, neglecting friction due to ring tension, would be:

$$F=f\times W,$$

and the power loss,

$$\text{Horse-power}=F\times2NS,$$

where f = the coefficient of friction (0.15 assumed; maximum 0.30);
W = the piston load on the cylinder (395 pounds).
$F=0.15\times395=59.3$ pounds;
$\text{Horse-power}=59.3\times2\times3\times150=1.6.$

The power loss with lubrication, in terms of horse-power, is not greatly below that without lubrication because of the considerable drag due to an expansive rubbing surface; but it is obvious that the lubrication has minimized the real and imminent danger of abrasion, which when once started proceeds at an alarming rate with the expenditure of much energy. Protection and decrease in power loss may both be attained under the lubricated condition with careful selection of the lubricant.

How to check the accuracy of the selection of viscosity.—The following method is difficult, tedious and time-consuming and requires expert manipulation. It is, however, the only known way to determine quickly and quantitatively the relative lubricating qualities of oils but slightly different in properties. The " Indications of Poor Lubrication," discussed in the succeeding section should be considered in connection with the method.

With a fixed " feed " (see Section 5, below, on " The Quantity of Lubricant Necessary ") and " compounding " of the selected oil, operate the engine under normal load conditions, keeping the load constant by a Prony brake or a dynamo working against an adjustable resistance. Determine the indicated horse-power (I.H.P.). Repeat with an oil lower in viscosity by 10 per cent, at 210° F.; then with an oil higher in viscosity by 10 per cent. Should the lower viscosity give a higher frictional load than the selected viscosity the latter may be insufficient to carry the load properly.

If the lower viscosity gives a frictional load below that with the selected viscosity, but not so much below as to make the difference in power loss significant, the selected viscosity is satisfactory.

If the power loss with the selected viscosity is higher than with the viscosity 10 per cent above, the viscosity of the selected oil is insufficient and trial should be made with an oil 20 per cent higher to supply data to permit a choice between the oils 10 per cent and 20 per cent above the original selection.

Indications of poor lubrication are vibration of the engine, the sound of metallic contact (groaning), scar marks on the cylinder (assuming mechanical adjustments are right), and difficulty in the manipulation of the valves.

Correct operation and good lubrication will be proved by absence of vibration or sound, accurate operation of valves, the presence of oil on the piston rod and on the cylinder walls (cylinder head off) and the minimum friction load as previously described.

2. **Whether oil should be compounded,** and to what extent, is determined, so far as the piston-cylinder needs are concerned, by the amount of moisture in the steam, although methods of feed have an influence. In answering this question, experience, with a little aid from the principle of surface and interfacial tension of liquids and solids is our only guide.

A wet surface is difficult to lubricate because water and metal surfaces have a strong mutual affinity and pure mineral oil floats on the water. It then becomes necessary to arm the oil with the means of breaking through the water film, displacing the water spread over the cylinder walls. Mineral oils compounded with fatty oils containing a small percentage of free fatty acid or other emulsifying agent will mix with water more or less readily. So far as lubrication is concerned the fatty oil has performed its function when the lubricant has completely covered the cylinder walls. Subsequently it becomes difficult for condensation to displace the oil, although probably it would be more difficult if the oil film on the cylinder walls contained no fatty oils or other emulsifying agent.

It is of advantage that water on the cylinder walls evaporates readily, leaving a clean surface to which oil will adhere; also that well-refined oil with a high flash point evaporates but slowly and once spread over the cylinder walls is easily maintained by very limited additions, unless the piston and rings have sharp edges and scraping (pushing) the oil before them fail to mount the oil and ride in the lubricated condition.

Oils for use in dry (saturated) steam conditions and particularly with steam carrying appreciable superheat, may be successfully used without compounding. Conversely, the greater the amount of moisture and the greater the need for emulsification within the cylinder, the greater the percentage of compound required. But it should be borne in mind that the good effects of emulsification do not increase directly with the percentage of fatty oil added, but at a lower rate.

The essentials for a satisfactory fatty oil for compounding are that it shall contain no non-volatile material because of the danger of accumulating in the cylinder; that it shall contain sufficient fatty acid to accelerate the speed of emulsification, but not so much as to endanger the metallic surfaces by corrosion (fatty acids attack iron and steel quite rapidly at elevated temperatures 300° F. and above); and that its viscosity shall be such as to cause the least lowering of the viscosity of the viscous mineral oil. Because it meets these requirements successfully and is readily obtainable "acidless" (so-called) tallow oil is most commonly used as the compounding agent. It has a viscosity of about 45 at 212° F. and an acid content of 0.5 to 1.0 per cent.[1] Five per cent of it will reduce the viscosity of a high-grade mineral cylinder oil of 175 seconds approximately 8 seconds, measured at 210° F. on the Saybolt Universal Viscosimeter. Reduction for other viscosities is approximately proportionate.

Compounding practice to-day ranges from 2 per cent to 15 per cent; most compounded oils contain about 5 per cent. Compounding over 8 per cent is uncommon, and generally speaking, costly and unnecessary. Many pure mineral cylinder oils are giving splendid results.

[1] Probably a much larger percentage of fatty acid, even up to 10 per cent, would function more satisfactorily without hazard of corrosion.

If a copious supply of a mineral cylinder oil were fed at the beginning of a run it would make an excellent film over the cylinder surface and could be maintained under correct methods of application with the minimum of feed. When conditions for making a film on the cylinder walls are good, the best film possible under the conditions is formed much more quickly by a copious supply of oil at the beginning of a run than the time required for destroying the film on cessation of oil-feed.

Condensation of steam carrying no superheat takes place within the cylinder to the extent of about 25 per cent of the total fluid delivered to the engine. This condensation probably does little harm to a well-formed lubricating film, as shown by the successful lubrication of cylinders receiving dry saturated steam with oil containing little or no compound.

Priming of boilers may account for the presence of as much as 3 or 4 per cent of moisture in the steam. Condensation along the steam line may produce a considerable amount of moisture. It is apparently this initial moisture carried into the cylinder at the maximum pressure that plays havoc with the oil film. The particles of water driven against the oil film at a high velocity tend to force the oil from its place.

Condensation within the cylinder may be obtained by G. R. Bodmer's formula:

$$\left(W = C\frac{S(T-t)}{L\sqrt{N^2}}\right),$$

in which W = weight of water condensed per minute;
T = mean admission temperature;
t = mean exhaust temperature;
S = clearance surface, square feet;
N = revolutions per second;
L = latent heat of steam at admission temperature;
C = Constant = 0.11 for high pressure, non-jacketed engines;
= 0.085 to 0.11 for condensing non-jacketed engines;
= 0.085 to 0.053 for condensing engines, jacketed except at the ends.

Condensation in pipes between the boiler and the engine (without separator) may be calculated with the help of the radiation data determined by the Mellon Institute and shown in the accompanying table.

$$W = \frac{PL \times H \times (T-t)}{L},$$

in which W = weight of condensate per hour;
PL = length of bare pipe of specific diameter;
T = steam temperature;
t = atmospheric temperature;
L = latent heat of steam in pipe.

For a 4-inch line, 200 feet long, assumed to be bare for half its length and well covered for the other half, carrying 150 pounds of steam across a yard, air temperature 50° F., the condensation per hour is:

$$W = \frac{100 \times 3.66 \times (366-50)}{857} + \frac{100 \times (3.66 \times .18) \times (366-50)}{857}.$$

$$W = 159 \text{ pounds}.$$

Radiation Loss in Bare Steam Lines

Pipe size	B.T.U. LOSS PER HOUR, PER LINEAR FOOT, PER DEGREE F. TEMPERATURE DIFFERENCE				
	80 pounds, 324° F.	120 pounds, 350° F.	160 pounds, 371° F.	200 pounds, 388° F.	200 pounds, 100° superheat
2	1.916	2.016	2.100	2.170	2.625
3	2.688	2.831	2.953	3.053	3.715
4	3.372	3.558	3.715	3.840	4.687
6	4.830	5.100	5.330	5.515	6.750
8	6.252	6.556	6.852	7.090	8.700
10	7.680	8.108	8.480	8.770	10.760

For well-lagged pipe, multiply by 0.18.

If this line carries steam to an 80-horse-power engine using 20 pounds of steam (steam and water) per horse-power hour, the moisture content due to line condensation will be about 10 per cent.

Correction of lubrication troubles arising out of this condensation may be made (*a*) by superheating the steam; (*b*) by use of a separator in the line near the engine; or (*c*) by use of a compounded oil.

Compounding at the rate of 1 per cent of fatty oil for each 1 per cent of moisture in the steam at the throttle valve, from a minimum of 3 per cent to a maximum of 10 per cent, is the only rational rule that can be given. The advantages of steam separators and superheat in making for economical steam consumption are reflected in lower costs of lubrication, as they reduce the amount of compounding required and the quantity of oil needed for satisfactory lubrication.

For conditions of excessive moisture, resulting in pools of water in the cylinder, the value of expenditures for cylinder lubrication is questionable.

3. **Conditions tending to modify " viscosity " and " compounding,"** as determined by methods discussed in the preceding sections, are:

(*a*) The conditions and method of feed;
(*b*) The use to which the exhaust steam is put.

The method of feeding the lubricant has a twofold influence: first, it determines the quality (viscosity and compounding) of the lubricant; second, it has a large effect on the rate of feed required to maintain efficient lubrication. There are in current practice two principles of application, viz., the " direct," which is employed to but a slight extent; and the " indirect "—the method of feeding into the inlet pipe, employed on most steam units. It is of importance that a sufficient supply of oil be delivered to that part of the cylinder carrying the load—the lowest fifth of horizontal engines.

In direct feeding the lubricant is supplied positively to the point where it is desired, namely the cylinder walls and valve seats. Two or more oil lines are led from a mechanical lubricator to as many points around the circumference of the cylinder, and enter at points where they are covered by the piston during a considerable portion of each stroke. There is consequently no direct loss of unused lubricant; all oil must have at least served for some part of the piston's journey; a similar arrangement is made for valve lubrication.

By the indirect method oil is usually fed drop by drop through a hydrostatic or mechanical sight-feed lubricator into the steam line, preferably some distance above the inlet valve and through an atomizer; it presumably becomes thoroughly mixed with the vapor, covers particles of moisture with an oil film and is carried by the steam to all internal parts of the me hanism, being deposited on the cylinder walls to form a lubricating film. How, after filling the entire available volume of the cylinder, it can be economically deposited in the short time available (even for a slow-speed engine, one stroke requires but half a second), is difficult to comprehend. Certainly a very large percentage of the lubricant must pass out in the exhaust on the return stroke of the piston.

The indirect method of application is varied in numerous ways, which divide themselves naturally into two classes—those in which the oil is fed into the steam or gas in a drop of " normal " size, and those which have arrangements by means of which the normal drop is subdivided (atomized) into many minute globules. The indications are that the latter scheme is the more effective.

The method of feeding oil into the steam line through a hydrostatic lubricator may necessitate a reduction of viscosity, as selected to suit the conditions of load, speed and temperature, because the steam cannot properly atomize the oil, or the arrangement of the oil inlet to the steam line does not permit it to do so. Viscous oil is, of course, more difficult to atomize than more fluid oil. At reduced engine loads the atomization naturally becomes inferior.

On the other hand the compounding may have to be increased, or the viscosity decreased, or both, to permit the oil to be fed evenly through the sight-feed lubricator, either because the sight-glass tube of the lubricator is small, or because the lubricator is subject to cool draughts, which increase the viscosity of the oil contained therein, and consequently increase the size of the drops formed at the orifice. Compounding, especially with 3 to 5 per cent of degras, helps this condition greatly.

More important still, as a condition modifying the specification, is the use to which the exhaust steam may be put. The desirable property of emulsification given by compounding becomes most troublesome when the condensate is used for ice-making, for boiler-feed water, for heating buildings, etc. Oil separators and filters then become a necessary part of the plant and the expense of their operation increases with the ability of the compounded cylinder oil to emulsify and stay emulsified, and with the quantity of oil used. In such cases the usage of the condensate decreases the compounding to the minimum, even to zero. In exceptional cases it has been found that a cleaner condensate and less clogging of the filter are obtained by the use of a smaller quantity of oil having as much as 3 per cent of compounding rather than by the use of a larger quantity of pure mineral oil.

4. **The chemical characteristics of cylinder oils**, particularly the ability to resist decomposition at high temperature (especially in the case of superheated steam engines), freedom from solids which tend to precipitate in the cylinder, and from excess of corrosive substances, e.g., fatty acids, constitute an interesting and somewhat important item in the selection of suitable oils.

" Tar " resulting from decomposition of oil, boiler compounds carried over with the steam by priming of the boilers, and foreign non-volatile solids incorporated with the oil, all of which work to make the piston rings bind in their grooves, are most harmful, cause excessive friction and, what is worse, cause rapid and ever-increasing scoring of the cylinders.

The effect of accumulated solids is disastrous; the remedies are exclusion of those substances added with a thought of improving the oil, greater care in treating boiler water, in preventing " priming " of boilers and in separation of moisture, and the use of clean, ashless oil.

The relation between the effects of decomposition of the oil and bad operation is generally obscured because the medium binding the rings contains some foreign solid, such as boiler compound.

It is definitely known that pure mineral cylinder oil and compounded cylinder oil precipitate carbonaceous, " tarry " solids at high temperatures, and indeed, seriously decompose when subjected to prolonged heating at temperatures above 600° F., and that differences exist between oils made from different crudes and by different modes of preparation, but, except in the lubrication of the cylinders of internal combustion engines, and in the condition set forth in the preceding paragraph, the harmful effects resulting from auto-precipitation or decomposition have been little evident in practice. The Germans, who first made extensive use of " superheat " in steam engines, employing temperatures upwards of 600° F., developed many tests, including the " asphaltum test," the " tar test," etc., to determine the presence and quantity of unstable, tar- and gum-forming constituents in cylinder oils. The tests are difficult to make, require extensive laboratory equipment and for the most part have questionable application.

The precipitation test, to determine the presence of suspended solids or an excessive quantity of asphaltum and like (tar-forming) substances is simple and sufficient. It is described completely in the chapter on testing methods.

The time element is of great importance in considering the probability of harmful oil deposits. The oil within the cylinder, with the exception of some that becomes lodged behind the rings, is constantly changing. If oil is fed at the rate of a quart a day, a quart a day goes out in the exhaust and through the stuffing box, and certainly most of the old oil is displaced by new. How long any drop of oil remains in the cylinder is problematical; but our ordinary experience is that if it passed the precipitation test, it will function without depositing any harmful substance.

A flash point of 100° F., above the average of the initial and final temperatures of the steam in the cylinder may properly be specified to insure freedom from admixture with oil distillates and as a check on the evaporative quality of the lubricant. The flash point is not emphasized, however, for the reason that it must be within reasonable bounds if the oil meets the " rate of change of viscosity with temperature " requirement.

5. **The quantity of lubricant necessary,** for good lubrication depends on the method of feeding, previously described, on the compounding, and, to a degree on the volatility of the oil and on other less tangible factors. The quantity is limited by the rate of expulsion with the exhaust, because of the danger of accumulations of the lubricant in the cylinders, and by the rate of drippage from the side walls of the cylinders to the lowest level. However, every set of conditions makes for variations in the feed, and the correct quantity should be determined. A method of determination follows:

Feed copiously (the limit of a hydrostatic lubricator) and take the indicated horsepower (I.H.P.) at normal load, keeping the load constant as outlined in the method describing the check on the selection of viscosity. Decrease the feed 20 per cent and retake the I.H.P. Repeat until " zero feed " is reached. Plot the I.H.P. against " feed " to find the lowest " feed " equivalent to the minimum I.H.P.

This method is accurate, but great care must be exercised to keep all factors, excepting change of feed, constant. It is tedious and time-consuming. Many indicator cards must be taken to obtain correct averages, and time must be allowed between changes of " feeds " to avoid the influence of the higher feed.

If care were exercised when starting the engine to drain all water from the cylinder and to feed oil copiously for a few minutes, the friction load would be lighter and the oil film built up and maintained more easily. Likewise in stopping the machine, the practice of cutting off the oil supply before throttling the engine is conducive to destruc-

tion of the oil film, a considerable portion of which would otherwise remain on the cylinder walls to function in restarting.

The following formulae give the average amount of cylinder-oil feed for engines of various sizes, and should serve as a guide in determining the feed for any particular engine.

J. H. Spoor, "Power" January 4, 1910, gives:

1.014 pints of cylinder oil per 1000 horse-power-hours;
0.97 pint of oil per 1,000,000 square feet of cylinder surface rubbed.

It is evident that with "indirect" feeding into the steam, the quantity of oil required will vary with the stroke and the square of the diameter of the cylinder for the reason that the oil is dispersed throughout the entire volume of the steam, much of it not reaching the surface of the cylinder, and so passes out with the exhaust.

The formula of Schmid, converted to units of pints and inches:

$$C = 0.000{,}002{,}355\ D \times S \times N$$

in which C is consumption per hour, in pints; D, cylinder diameter in inches; S, stroke in inches and N, the R.P.M.

A more rational formula, involving the volume of the cylinder and applicable to "indirect" methods of feed is:

$$C = 0.000{,}000{,}1\ D^2 \times S \times N$$

For "direct" feed the quantity should be proportional to the diameter and length of the cylinder, being a function of the surface evaporation. For direct feeding the following formula is proposed:

$$C = 0.0003\ D \times S$$

INTERNAL-COMBUSTION ENGINE CYLINDER LUBRICATION

The destructive action of the temperatures of combustion, which are produced in the cylinders of oil and gasoline engines and which act directly on part of the lubricating film, is the *chief* factor which distinguishes the problems of the lubrication of the cylinders of these engines from those of steam engines. The method of feeding the lubricant to the cylinder walls constitutes another difference. In the case of the internal-combustion engine this is done directly, by splash or positive feed; in the case of the steam engine it is commonly done with steam. Finally, nearly all combustion engines carry the connecting rod thrust directly on the cylinder walls, whereas steam engines are provided practically universally with slide blocks for this purpose.

Mineral oils decompose rapidly at temperatures just in excess of 600° F., and oxidize (thicken) slowly at temperatures well below 600°. The longer the exposure to heat the greater the destruction or oxidation. Time is a fundamental factor in the behavior of lubricating oil in the cylinder of an internal combustion engine.

The volatilization of oils increases as the temperature increases. Atomization of oils, or the mechanical subdivision of oil into very small particles by splashing about, as on the top of a piston, increases as the viscosity decreases. The viscosity decreases as the temperature increases.

This atomization and volatilization of the lubricating oil in the cylinder above the piston is assumed to account in large measure for the consumption of oil in this type of machine. As long as it is found impossible to prevent oil from getting into the

combustion chamber, this consumption of oil will be a necessary condition of successful operation, for the following reason: All oils decompose at the temperatures of the gases of combustion above the piston, if exposed to those temperatures for a sufficient time; if by atomization and volatilization the oil passes out of the cylinder with the exhaust gases before the destruction time-period of the oil has elapsed, destruction, with its products, carbon and " oil gum " has been prevented, and the cylinder, piston, spark plugs and valves remain clean and operative, except for such fouling as may be due to incomplete combustion of the fuel. It is obvious, then, that an oil which is difficult to atomize or volatilize will function longer as a lubricant, but at the expense of the trouble arising from greater amounts of decomposition products of the lubricant occasioned by its longer exposure to high temperature.

The rate at which a given oil will volatilize above the piston (and so pass out in the exhaust, undecomposed) is fairly well fixed for that particular oil. Therefore, if oil is fed to the cylinders so fast that this rate is exceeded, some oil is exposed to high temperatures for an abnormal period, decomposes and causes the common carbon trouble. The rate of feed of oil is an important consideration. The control of the amount of oil fed to the cylinders of nearly all stationary oil and gas engines is fairly satisfactory, and it is to be noted particularly that troubles arising from carbon deposits are much less common with this type of equipment than with automobile engines, although more attention is given to the selection and refining of oils for the latter machines. Unfortunately, the lubrication systems of the great majority of automotive engines permit little control of the amount of oil supplied to the cylinders, and some oil is exposed for too long a period to high temperatures.

No oil can long withstand the destructive action of the heat; therefore it is more satisfactory to employ an oil with higher rates of atomization and volatilization in order to enable it to pass out of the cylinder before decomposition has set in.

The oil which best meets this paramount requirement is an oil of lowest boiling range, that is, one whose component hydrocarbon compounds have as nearly as possible the same boiling point, or an oil in which the gap is least between the lowest- and the highest-boiling constituents. In order that it may volatilize in the combustion space above the piston, it should be an oil which is capable of being distilled completely, easily and quickly in the ordinary refining process of distillation with steam, without decomposition.

Preferably also, for reasons given above, the internal-combustion engine oil should be of comparatively low viscosity. There are no known reasons why the oil should be of high viscosity when used in an engine in good repair.

The function of the cylinder lubricant is to prevent the piston and cylinder from " freezing " and to do this without undue retardation of piston travel. The ability of the lubricant to perform this function depends on its viscosity at the working temperature. The viscosity must, of course, be sufficient to carry the thrust of the connecting rod through the piston against the cylinder walls. This applies only to trunk-type pistons; in the horizontal crosshead type of oil or gas engine the viscosity must simply carry the weight of the piston and rod on the cylinder.

The viscosity necessary to carry the piston load (thrust) is very low, because the load is of small magnitude. The maximum piston thrust in automotive types of internal combustion engines is about 15 pounds per square inch for the full load condition. The maximum thrust for ordinary operating conditions is considerably less; and the average thrust for the complete cycle of piston motion for ordinary operating conditions is almost insignificant. It is to be remembered that the maximum thrust is of momentary duration.

The most fluid household lubricant employed for the lubrication of sewing-machines, lawn-mowers and similar equipment, if it could be kept at ordinary tem-

peratures, would be quite viscous enough to carry, with a reasonable factor of safety, the low pressures met in the operation of automotive and other internal-combustion engine cylinders. It is assumed, of course, that the clearance between the piston skirt and the cylinder walls is normal—that there is no lost motion perpendicular to the axis of the cylinder giving rise to a "slapping" of the piston.

However, whatever the viscosity necessary to carry the piston load, it must exist at the working temperature; this working temperature is acquired from the heat retained by the oil film between the cylinder and the piston, which is the difference between the quantity of heat the oil receives from the piston and that which it loses to the cylinder walls.

It is very probable that the average temperature of the oil between the piston and the cylinder walls is well below the boiling point of water. Certainly the oil temperature must be between the temperature of the cylinder-jacket water and the temperature of the metallic sides of the piston. The temperature of the jacket water is easily determinable; it is, of course, generally well below (sometimes 150° below) the boiling point of water. Until recently the temperatures of the several parts of the piston have been problematical.

Frank Jardine and Ferdinand Jelle [1] have published what is believed to be the first result of the actual measurements of piston temperatures by electrothermal methods. They show that the maximum temperature of the piston of a gasoline engine at the top of the skirt is 290° F. and at the bottom of the skirt about 170° F. For the condition of cold-jacket water (outlet, 58° F.) these temperatures were 127° and 113° respectively. In all cases there is a temperature drop from the pistons to the jacket water through the oil film and cylinder walls.

Obviously the oil film will possess a lower temperature than the piston. Oil is a poor conductor of heat; therefore, it is hardly to be assumed that an appreciable portion of the temperature of the oil between the piston and the cylinder is due to the heat of combustion except as obtained from the piston. According to the experiments of Jardine and Jelle the average temperature of the piston skirt is about 200° F. In this connection it is to be noted that the temperature of the top of the piston head is upwards of 650° F., a temperature quite high enough for producing rapid decomposition in oil which persists in clinging to this part of the piston.

The speed of piston travel, frequently upwards of 1000 feet per minute, is significant for two reasons: (1) high linear velocity, with proper rounding of the advancing edges of the piston, tends to force the piston to ride upon a film of oil; (2) friction loss due to molecular retardation increases in proportion to the viscosity of the lubricant and the velocity of piston travel. Both reasons, therefore, point to the advisability of using an oil of minimum viscosity consistent with the ability to support the piston load. The viscosity at the working temperature which will carry the piston thrust with a reasonable factor of safety has been determined by the very satisfactory method of long experience in passenger car and truck engines, and in stationary oil and gas engines used for generating electric power, manufacturing ice, etc.

Viscosities ranging from 44 to 50 seconds Saybolt Universal at 210° F. (roughly equal to 185 to 280 seconds at 100° F.) have given altogether satisfactory service; indeed this range has included the great majority of internal-combustion engine cylinder oils marketed in America. An oil with viscosity as low as 40 seconds Saybolt at 210° F. (100 seconds at 100° F.) has been satisfactorily employed, and probably gave a very reasonable factor of safety. For racing engines, using a pressure-feed lubricating system, an oil of approximately 42 seconds at 210° (140 seconds at 100° F.) gave superior speed and suitable protection to the engine when compared with an oil of 50 seconds Saybolt at 210° F.

[1] Journal of the Society of Automotive Engineers, May, 1921.

Broadly, any viscosity between 44 and 50 seconds Saybolt at 210° (185 and 280 seconds at 100° F.) is considered satisfactory for the lubrication of the cylinders of internal-combustion engines, if the piston pressures do not exceed those discussed above.

It is to be noted that, in general, particularly for automotive engines, the cylinder oil also serves as bearing oil. The influence of bearing requirements is discussed in the example which follows:

One other consideration merits attention: the differences existing in the mechanical conditions which determine viscosity are greater between the "No load, slow speed" (idling) condition and the "Maximum load, high speed" (full load) condition for any particular automotive engine than are the differences in the mechanical conditions (pressure, speed, temperature, clearance, feed) between different makes of engines. Therefore there is little occasion to have materially different oil specifications for engines which are designed essentially according to the same rules.

Lubrication Analysis of an Internal-combustion Engine Unit: Typical Automobile Engine

Four-cylinder, $4\frac{1}{2}$-inch bore; $6\frac{3}{4}$-inch stroke, 1000 R.P.M.

The case of the automotive engine is of particular interest because of the great number of these units—10,000,000 engines in this country with a total rated capacity upwards of 250,000,000 horse-power compared to 60,000,000 horse-power generated by steam, oil, gas and water in the United States for industrial purposes; also because of certain misconceptions concerning automobile lubrication, and because, by good lubrication, great economies can be effected in the use of that important American resource, gasoline.

The automobile engine presents an interesting case because of the complexity of the fundamental conditions of bearing pressures, rubbing velocities, temperatures and method of feeding, which are further complicated by more or less contamination of the lubricant by gasoline, by the carbonaceous products of decomposition, and by the accumulations of road dust.

It will be found that if we can satisfy the conditions of lubrication for the cylinders, crankshaft bearings and crank-pins, we shall have no difficulty in lubricating other parts of the engine, such as camshaft bearings, where danger of breakdown or power loss is less imminent.

Four-cylinder engine data:

Bore, $4\frac{1}{2}$ inches.
Stroke, $6\frac{3}{4}$ inches.
Speed, 1000 R.P.M. = 655 feet per minute.
Crankshaft diameter, $2\frac{1}{2}$ inches.
Main bearing lengths, Front —$2\frac{3}{8}$ inches; Area = 5.94 square inches (omitting filets).
Center—$3\frac{3}{8}$ inches; Area = 8.45 square inches.
Rear —$3\frac{1}{16}$ inches; Area = 7.67 square inches.
Crank-pins, $2\frac{1}{2}$ inches by $2\frac{1}{2}$ inches; Area = 6.25 square inches.
Temperature of oil in circulating system = 130° F.
Temperature of jacket water = 150° F.

According to an article by Otto M. Burkhardt,[1] in which the method of determining total bearing pressure is given, and from which the following data on

[1] Journal of the Society of Automotive Engineers, April, 1919.

bearing pressures are selected, the condition of operation involving high speed and maximum power produces the greatest average bearing loads. Likewise, this condition produces the greatest piston thrust.

The bearing pressures which are presented combine the pressures due to gaseous mixtures, centrifugal forces and inertia forces.

Average piston pressure during expansion stroke, per cylinder	2380 pounds
Average piston pressure during compression stroke, per cylinder	272.5 pounds
Maximum pressure front and rear bearings	2945 pounds
Maximum pressure center bearing	2690 pounds
Maximum pressure crank-pin bearing	4075 pounds
Average pressure front and rear bearings	1000 pounds
Average pressure center bearing	1700 pounds
Average pressure crank-pin bearing	1230 pounds
Average bearing unit pressures:	
Front	168 pounds per square inch
Center	201 pounds per square inch
Rear .... 131 pounds per fly wheel included,	145 pounds per square inch
Crank-pin	197 pounds per square inch

The momentary duration of the maximum pressures, and the continuously changing direction of the resultant of the several pressures on the bearing warrant the use of average, instead of maximum, bearing pressures. Further, the continuously changing direction and magnitude of the bearing pressure permit the reduction of the " normal " factor of safety, as discussed on page 639, to one-half the usual value.

The engine having a force-feed system of lubrication, a factor of safety of 1.7 is taken. Solving for a suitable viscosity for the most severe condition, namely, 201 pounds per square inch at 655 feet per minute rubbing speed, we obtain:

$$\text{equivalent pressure } 201 \times 1.7 = 342 \text{ pounds per square inch.}$$

The corresponding viscosity from Fig. 15 equals 80 seconds Saybolt at 130° F. From Fig. 8, by interpolation, the viscosity of the desired oil is 140 at 100° F.

A larger factor of safety may be employed to compensate for loss of viscosity by the dilution of the lubricating oil by unburned fuel.[1] Where economy of operation is desired it is questionable, however, whether the factor should be increased much in excess of 50 per cent of the figure given in the present example.

The piston thrust on the cylinder walls may be determined graphically by plotting the triangle of forces thus: the base of the triangle proportional to the total force on the piston at that point in the stroke at which the crank and the connecting rod make a right angle, the hypothenuse of the triangle making an angle with the base equal to the angle made by the connecting rod and the center line of the cylinder. A perpendicular is erected to complete the triangle. The length of the perpendicular is proportional to the piston thrust, in pounds:

For a connecting rod 14¾ inches long we have:

Stroke for greatest angularity of rod, 44.4 per cent = 79.4°.
Maximum total piston pressure at 79° = 1615 pounds, explosive stroke.
Maximum piston thrust, vertical component = 383 pounds, explosive stroke.

[1] See G. A. Kramer on Dilution of Engine Lubricants by Fuel in the Journal of the Society of Automotive Engineers, February, 1920.

Piston diameter, 4½ inches.
Piston length, 6 inches.
Piston area, 27 square inches. (Projected area, $D \times L$).
Maximum unit pressure on cylinder, 14.15 pounds per square inch.

The average unit pressure on the cylinder for an entire cycle is obviously well below this figure.

The bearing requirements call for an oil of 140 viscosity at 100° F. Because of the low piston thrust it is safe to assume, from practical experience, that if this oil of 140 at 100° F., possesses a viscosity of 42 or higher at 210° F., the viscosity requirement of the cylinders will also be met.

LUBRICATION SYSTEMS AND BEARING DESIGN

The selection of lubricating oils, particularly journal-bearing oils, depends in a large measure on the quantity of the oil fed to the bearing, which in turn is largely controlled by the equipment employed to apply the lubricants. Modern pressure-flood-feed systems employing some means of oil recovery and purification, permit the use of the minimum viscosities consistent with the bearing pressures and velocities, at the same time insuring safety and a continuous saving of power. The saving of power is often very important because it permits increased production without capital expenditures for power-generating machinery. Reference should again be made to the feed-friction curve, Fig. 11.

The catalogues of manufacturers of lubricating devices and systems are suggested as most excellent literature for a study of available and proved oil-application equipment; standard and special systems and lubricators are adaptable to almost any set of conditions.

Oil grooves in bearings.—Because all lubricants work more satisfactorily on rubbing surfaces designed with a knowledge of lubrication, and because lubricants correctly selected on the basis of accepted theory and proved practice may sometimes fail to give satisfaction because of omission in the design or construction of a detail like oil grooves or chamfered edges, the following paragraphs on grooving, taken from *The Textile World Journal* are inserted. Otherwise this section would be omitted on the ground that the chapter on lubrication is intended as a guide to engineers in the selection of lubricants for existing machinery. The author realizes that the engineer cannot always determine the character or extent of oil grooves, piston-ring bevels, etc., and usually is not in a position to change undesirable conditions even when they are discovered.

"Some engineers are of the opinion that oil grooves in a bearing are detrimental, in that they reduce the bearing surface and offer a means of escape for the oil.

"This theory loses sight of the fact that means have to be provided for getting the oil to and distributing it over the bearing surfaces, and for retaining the oil in the journal.

"It is these functions which oil grooves perform so successfully that make them indispensable. We have seen many instances where the theory that oil grooves were unnecessary and detrimental was followed, and which resulted in continual trouble from heating of the bearings until the operating engineer took it upon himself to provide oil grooves, after which no heating or kindred troubles were experienced."

Functions of oil grooves.—The functions which oil grooves are intended to perform are:

(a) To provide a receptacle for receiving the oil into the bearing.

(*b*) To distribute the oil lengthwise of the bearing, so that the moving surface passing the grooves or chambers is bathed in and coated with oil.

(*c*) To distribute oil from the grooves and chambers over the bearing surface.

(*d*) To catch oil which has squeezed over towards the ends of the bearing and thus prevent it from working out of the bearing entirely; and

(*e*) To return such oil to the center of the bearing, where the cycle of distribution, catching and returning it again to the center of the bearing, is again started and repeated.

"**Instructions for grooving.**—In grooving bearings it is of the greatest importance that the following general instructions be observed:

"1. Do not groove both the male and female surfaces of a bearing; grooving one surface is right; grooving both surfaces is wrong. The female or enveloping surface is the one which should be grooved. There are a few exceptions to this rule, among them being the bearing surfaces of the shoes of a crosshead, which are grooved, and not the bearing surfaces of the guides; the bearing surface of shafting or sleeves which work in long solid bearings and which are grooved on account of the bearing being too small in diameter and too long to permit internal grooving.

"2. Make the width and depth of grooves liberal. It is customary to err in the direction of making them too narrow and too shallow, with the result that they clog up readily. If a bearing which is equipped with shallow, narrow grooves heats slightly at any time, the grooves become plugged, lubrication ceases, and it is then necessary to shut the engine or machine down and dismantle the bearing in order that the deposit can be removed from the grooves. It is difficult to fix any general rule for the dimensions of oil grooves which agree closely with the best practice, but for width of groove it is well to multiply the diameter of shaft or pin in nearest even inches by 0.01 and add $\frac{1}{16}$ inch. For depths of groove take half the width. Well-designed bearings will have a sufficient thickness of babbitt lining or bushing to accommodate safely the above depth of groove.

"3. Round all corners of grooves well. This is important as it insures the flowing or 'wedging' of oil from the grooves into the space between the rubbing surfaces. An oil groove having sharp, square edges will scrape oil from the ungrooved surface of the journal instead of allowing a fine film of oil to squeeze from the oil groove into the space between the rubbing surfaces. This rounding of the edges of oil grooves is one of the most important factors in securing successful lubrication of a bearing and is the one which, in so many instances is neglected entirely. If an engineer desired to provide a number of sharp scrapers to remove the oil from the ungrooved surface of a journal, he could not do it more effectively than by the use of sharp-edged oil grooves.

"4. Be careful to arrange the oil grooves with particular reference to the direction of motion of the ungrooved surface on the grooved one. This is of the greatest importance, because it is this movement of one surface on another which effects the movement of the oil in the bearing, and if a bearing is grooved for the wrong direction of motion the grooves will work the oil out of the bearing instead of towards the center of it. Gravity has little effect on the movement of oil in a journal.

"5. Do not extend the grooves too close to the edges of the bearing surfaces, as this allows the oil to escape from the journal. As a general proposition, keep grooves away from edges of bearing surfaces from $\frac{3}{4}$ to $1\frac{1}{2}$ inches, depending on the size of the journal.

"6. Grooves and chambers should be smooth and regular."

There are many different arrangements of oil grooves in use; some of them are planned with due regard for what they are intended to accomplish; others are planned without any conception of what oil grooves are intended to do or how they are to do it; and others are not planned at all. Oil holes and oil grooves are seldom shown

in the drawings, but their design is generally left to men who, while they are good shop mechanics, know little or nothing of the operation and lubrication of machinery. Is it any wonder then, that bearing troubles are experienced and that operating engineers in many cases find it necessary to use much oil with less efficiency, when if oil grooves had been correctly designed, a proper amount of suitable oil would work better and at much less cost.

In the present writer's opinion oil grooves are unnecessary and undesirable, provided the bearings are well made; for low-pressure lubricating systems, provided that the lubricant is fed at such point or points of minimum pressure on the bearing that it is carried by the journal to the area of greatest pressure between the journal and the bearing; and for high-pressure systems that the oil is applied at a point or points within the area of greatest pressure on the bearing. It is desirable in both systems that at least one point of application be at the center of the length of the bearing in order that the oil may have the maximum effectiveness as it spreads towards both ends of the bearing.[1]

Books on machine design and particularly on bearings are suggested for those who are interested in design or further study of the subject.[2]

Reciprocating parts need special attention with respect to the character of the "advancing edges" of the moving part, as in pistons, piston rings and crosshead shoes. Sharp edges are taboo. Sharp edges act as scrapers; they clean the oil from the stationary surface and prevent the insinuation of oil under the moving surface. An ice-skate with a very sharp toe will not cut into the ice and impede the progress of the skater more readily than a sharp piston ring will scrape oil from a cylinder wall. For service both the toe of the skate and the edge of the ring must be rounded slightly, not so much as to appreciably decrease the bearing surface, but enough to enable the movable part to ride up and on the oil wave created in front of the moving part as the latter pushes the excess oil forward.

There is considerable pressure built up just at the line of contact between the bevel of the reciprocating part and the bearing surface, which increases with increase of viscosity and increase of velocity of travel. The inertia of the oil wave and the momentum of the moving part represent opposing and therefore cumulative forces; the lubricant tends to stay in the position in which the moving part meets it when the latter starts to push it forward; the resultant force consequently tends to raise the moving part, just as a wedge whose edge is inserted under a block, will raise the block. Those who have learned the art of scooping up oil with a quick forward "snap" of a shovel have a ready illustration. A slow motion of the shovel simply shoves the oil ahead; a quick motion of even a blunt shovel causes the oil to "build up" in front of the shovel before the most distant part of the "puddle" has moved from its position under the force of impact with the shovel. The cutting action of the edge of the shovel has been disregarded in this illustration.

In conclusion, the essentials of successful lubrication may be compared with the familiar and well-understood principles of satisfactory personal nutrition, in order that the reader may remember the former. Both sets of fundamentals have the following points in common:

1. Selection of the grade of lubricant suited to the particular conditions. (Not all foods satisfy or "agree" equally with all individuals.)

[1] See also "The Lubrication of Bearings," A. L. Campbell, Eng. Mag., Vol. 36, pp. 469–476, December, 1908, on method of applying oil to bearings at points of least pressure.

[2] See particularly "Bearings," by L. P. Alford; "Bearing Design" H. F. Moore, American Machinist, Vol. 36, pp. 1350–53, 1903; and J. F. Nicholson, American Machinist, Vol. 31, pp. 46–80 1908.

2. A sufficient quantity of lubricant to replenish that lost from the bearing in the course of operation (or of food to replace energy lost in work).

3. A correct application of lubricant to insure it "reaching the spot" (or the proper mastication of food to permit of the greatest economy of assimilation)

NOTES ON GREASE LUBRICATION

How to select a lubricating grease for a given set of conditions is the real problem, for which the author, at present, knows no rational solution which can be crystallized in writing. Even the laws of lubricated friction, expressed heretofore, and applicable to oil lubricants, can be applied to grease lubrication only in a general way, for the reason that the consistency (viscosity-resistance to movement) of greases appears to vary with the amount of motion set up among the grease particles by the relative motion of the bearing surfaces.

In general, it is inadvisable to employ grease for lubrication where oil could be used just as conveniently, especially in high-speed equipment operating continuously. Indeed, in such machines, it is frequently desirable to take some little pains to apply and recover oil lubricants. Where the cost of power is a prime consideration it is very questionable whether grease should ever be applied, except to certain classes of bearings hereinafter mentioned.

The conditions which warrant the application of grease lubricants may be classified as follows:

1. In bearings for which the total frictional loss, even with grease, is a negligible quantity (compared to the frictional losses at other parts of the machine), for example in the Stephenson reversing gear.

2. When the operation of the bearing is intermittent, as with the pinions and gears of a bascule bridge. It is obvious that oil lubricants would flow from the bearing surfaces between applications made at reasonable intervals and that labor would be required to replace them.

3. When the application of oil, either because of an unavoidable condition or inadequacy of the lubricating system, creates a hazard, by splashing or dripping from the lubricated surfaces, resulting in injury to fabrics in process of manufacture, as in textile mills, or source of discomfort to workmen.

4. When applications of oil could be made only at such long intervals as to permit abrasion of the surfaces in the period just before each application of lubricant. This condition obtains with many easily accessible bearings because of lack of interest, on the part of workmen, in the economical operation and maintenance of the machine; and it is always present when the bearings are difficult of access. Under these circumstances, grease lubrication requires the minimum of attention and the minimum of lubricant. Naturally, it produces the poorest results from a frictional viewpoint.

5. For certain bearings operating at very slow speeds or with great clearances, wherein the frictional coefficients will be lower with grease applications, for the reason that the greater film thickness maintained by the grease more than counterbalances the greater resistance due to its high consistency.

6. In certain types of bearings, notably in steel and paper mill and chemical factory equipment, operating at very high temperatures and not equipped with a suitable oil-applying and recovering attachment.

7. As a shock or noise absorber, as in the operation of gearing in sugar and steel mills, especially of gearing with worn or poorly fitted teeth.

The principal requirement of a good lubricating grease is:

1. That it shall "stay put."—It must possess great power of adhesiveness for the bearing surfaces, otherwise it loses its value as a more practical lubricant than oil in the cases enumerated above.

Supplementary requirements are as follows:

2. Stability.—It should retain its physical properties during storage and use. This is a requirement difficult or impossible for soap greases to fill perfectly, as by their very nature, they are subject to chemical change with exposure to high temperatures, to the oxidizing action of air, and indeed to a separation of the oil and soap constituents.

3. A consistency compatible with reasonable "stick-to-it-ive-ness," and with the minimum of power wastage.—The lower the consistency the lower the power loss, other things being equal. The degree of hardness (resistance to deformation by pressure) is the only measure available for "consistency."

4. A melting point suited to the temperature at which the grease must function.—It is obvious that if the melting point is too low, the grease will melt, run off the bearing, and be little more useful than an oil; if the melting point is too high, the grease will not spread itself effectively over the surfaces to be lubricated.

5. Freedom from non-lubricating "fillers," and from alkalies, acids or gritty substances which would corrode or abrade the bearing surfaces.—The importance of this requirement, "purity," is probably generally appreciated, but the difficulty of detecting injurious or useless ingredients is not understood. In this respect grease lubricants are not as readily susceptible as oil lubricants to valuable rough assays which can be applied equally well by the chemist or the lay worker.

The idea that greases will carry greater bearing pressures than oils has its only basis in the fact that greases ordinarily have greater consistency (viscosity) than oils. There are, indeed, few cases of lubrication in which it is necessary to consider grease because of its ability to carry high loads. The rate of feed, the attention required for applications, the stability, the freedom from harmful substances and the minimum consistency permissible with the foregoing factors are our basis of selection of lubricating greases.

The selection of lubricating greases for specific purposes has been greatly simplified by the terminology developed with the art of grease lubrication. Terms have been coined which describe the general characteristics of a grease, and by custom, the use to which that type of grease should be put. Differences exist, of course, among the numerous members of each family or class of greases, and these differences permit a range of selection within several of the more important groups of greases.

The principal groups or families of greases follow:

1. Cup and graphite greases.
2. Gear and pinion greases and glazes.
3. Elevator and plunger-pole greases.
4. Cold neck greases.
5. Hot neck greases.
6. Axle and journal greases.
7. Special greases, e.g., yarn and asbestos greases.

To fully comprehend the principles governing the proper selection of a grease for specific work it is necessary to understand something of the general make-up of greases.

What lubricating greases are.—An ordinary pure mineral lubricating oil, when chilled to a temperature several degrees below its "pour point," is essentially a lubricating grease in appearance, in texture, and in lubricating quality. It will behave like grease when placed in a device designed to apply lubricating grease to a bearing. This, of course, applies to the physical characteristics of the oil. It is "slippery" (to the touch

or when interposed between two parallel surfaces moving relatively), it is solid, i.e., it will not pour from a container or flow through a lubricator without the application of heat or pressure, and as long as it is kept at a temperature below its pour point it retains the properties just enumerated. It does not, for example, lose its unctuous properties by exposure to air, through the loss of a constituent essential to its greasiness, as would a "slippery," "greasy," film of clay and water. Pure petroleum oils of very high viscosity and high pour point, e.g., petrolatum and heavy still residuum, constitute, indeed, a distinct class of lubricating greases.

Chemically, there is a great difference between most commercial lubricating greases and the "frozen," oil above mentioned. The greases are essentially intimate mixtures of a soap and a fluid lubricating oil, the latter being held in the former somewhat as linseed oil is held in a well-kneaded putty. The soap acts as a "sponge," to the oil; and the mixture is sufficiently complete, mechanically, to give the appearance and conduct of a homogeneous mass.

Lubricating greases may be constituted as follows:

1. Pure animal fat, e.g., tallow.
2. Pure mineral grease, e.g., the petrolatums and petroleum greases of commerce.
3. A mixture of animal fat and mineral grease (Nos. 1 and 2).
4. A mixture of a soap and a mineral oil. The soap may be made with lime and a fat or fatty oil, e.g., tallow, cottonseed oil, lard oil, horse oil, etc., giving rise to the so-called calcium or cup greases; or with soda or potash and the fat, producing in the latter case the fiber or sponge greases, so called from their fibrous, spongy character.
5. A compound of heavy petroleum residuum with rosin, pine tar or both.
6. Cup grease (No. 4) to which have been added petrolatums (No. 2), or special waxes for producing hardness, graphite, asbestos or wool fibers for producing body, heat-resisting quality or resilience, as for example, in a yarn grease for use in the well of a car journal.

It is obvious that a multitude of variations of the above classes, with respect to character of constituents, may be made at the will of the manufacturer.

Differences between the greases belonging to any one class, especially to Class No. 4 above, which is the commonest, are produced legitimately by varying:

(a) The percentage of soap and oil.
(b) The viscosity of the incorporated oil.
(c) The character of the fatty oil, e.g., tallow, rapeseed, cottonseed oil, etc.

These chemical or constitutional differences produce physical or lubricating differences. Ordinary cup grease made of lime soap and a mineral oil of approximately 100 seconds viscosity, Saybolt Universal at 100° F., will vary in consistency from what is known in the trade as No. 0 Cup grease to No. 5 Cup grease, and in melting point from approximately 120° F. to 185° F. The soap content for this range of greases will vary from approximately 13 per cent for the No. 0 Grease to about 24 per cent for the No. 5 Grease, the remainder of the grease being composed of pure mineral oil and 1 to 3 per cent of moisture.

The miscibility of lime soap and mineral oil is much greater than that of soda soap and mineral oil. For this reason the former blends produce the smooth, unctuous "cup," greases, and the latter make the stringy, doughy "sponge," greases. Unquestionably, the former are superior as lubricants in ordinary journal-bearings. The latter have, however, the advantage of higher melting points and the important advan-

tage that upon being melted and cooled they return to their original consistency. Lime-soap greases are prone to separation of the oil and soap on heating to temperatures approaching, or in excess of their melting points. Soda-soap greases or sponge greases are to be looked upon as shock absorbers for many gears and similar equipment, rather than as unctuous, friction-reducing lubricants.

Chemical analysis of greases is generally of little avail except to protect the buyer against flagrant attempts at fraud through the incorporation of much water or of "fillers," with the grease, or to guard against the presence of corrosive substances in the grease. Fillers which may be used and which are without lubricating value, or of negligible lubricating value, are wood pulp, ground cork, talc, china clay, barytes, gypsum and asbestos. The last-named may be added for the purpose previously mentioned. Mica and graphite, particularly the latter, have decided lubricating value and are sometimes incorporated in greases for the purpose of improving the condition of the bearing surfaces.

Corrosive substances in grease are detected readily by means of a highly polished copper plate, which upon being immersed in the grease from one to several days at room temperature, will show by loss of polish the presence of injurious or objectionable corrosive substances.

The method by which grease is to be fed to a bearing is an important factor in the selection of the grease; for example, if the grease is to be fed by gravity, it must have a very low consistency; if it is to be fed by hand-feed cups, a medium consistency is required, while the use of powerful screw-feed cups permits higher consistencies. Some large bearings in paper mills are lubricated by a block of grease which rests upon the journal and is gradually applied to the latter by abrasion. It is obvious that such grease must have a high consistency. A bearing may be fed through a cup in which the grease is slowly melted by the heat transmitted to it from the journal by a copper rod which rides upon the journal. In this case the melting point of the grease must be such as to suit the condition. What this melting point may be can be determined only by experiment. Pinion greases, on the other hand, may be required to possess such adhesiveness, when on the gears in thin layers, that they are quite solid in the container in which they are delivered and require to be heated to the melting point before an economical application can be made.

More specific selections of lubricating greases follow:

1. For journal-bearings and other high-grade machine parts in which friction loss is a real consideration—cup greases. These will be lime-soap greases of a consistency and melting point selected to meet the particular conditions of method of feed (grease cup) and temperature under consideration.

2. For journal-bearings, which are pitted or possess large clearance— graphitized cup grease, similar to the preceding cup grease, but containing, in addition, from 5 to 20 per cent of flake graphite.

3. For ball-and-roller bearings—pure petroleum greases, preferably a highly refined petrolatum or a neutral mineral oil of low viscosity if the bearing is constructed to retain oil.

4. For gears and pinions.—(*a*) Enclosed in an oil-tight case—a pure petroleum grease of very low consistency. Indeed, an oil with a viscosity of approximately 150 seconds Saybolt Universal at 212° F., fluid at temperatures down to 35° F., may be used.

(*b*) For gears requiring a very adhesive grease which is really a protective glaze or noise-reducer—gear or pinion grease, a heavy, sticky petroleum residuum compounded with rosin.

5. When the grease is to be subjected to the action of water, as are elevator and plunger pole greases—greases carrying these or similar names and being essentially compounds of pure petroleum and pure animal greases. See No. 3 above.

6. For cold necks and other rough mill bearings—cold neck grease, a viscous, tacky, black or dark-colored grease, basically a compound of lime soaps of resinous acids and viscous petroleum residuums.

7. For hot necks and other rough mill bearings operating at high temperatures—hot neck grease, a grease of high melting point and high consistency, capable of adhering to journals at high temperatures. It is similar in general properties and make-up to cold neck grease, the proportions of the residuum and soap being varied to produce a higher melting-point grease.

8. For axles and rough journals—axle grease, a lime soap of resinous acids compounded with a viscous petroleum base.

The variations in the consistency and melting point of greases, within their minimum and maximum limits, are infinite. Consistencies vary from those of the stringy oils containing up to 7 per cent of aluminum oleate up to the hardest, almost brittle, special cup grease; melting points vary from about 100° F. up to 400° F. Unquestionably, the selection of the most suitable grease for a given set of conditions can be most expeditiously made by the grease manufacturer who has been supplied with the requisite data on working conditions.

THE FORMULATION OF SPECIFICATIONS

Specifications for lubricating oils should never be more rigid than the conditions of use demand. Complete specifications covering all of the physical and chemical characteristics of an oil are seldom, if ever, needed to insure a satisfactory lubricant. Such specifications tend strongly to increase the cost of the lubricant; and, unless formulated by an oil chemist, may involve combinations of properties which cannot be economically produced from any known raw material by any known process of refining.

Specifications should be based primarily on the determined conditions of use, as described under the section dealing with the factors involved in the selection of lubricants; secondarily, on a consideration of the combination of physical and chemical properties which may economically be produced from a given crude oil; and finally, on a consideration of those properties such as " color," which permit the ready determination of the existence of water or dirt, or which affect the degree of fire hazard at storage, or satisfy the esthetic sense and idiosyncrasies of the user.

To have a specification for an oil of a given class, for example, engine oil, which is expected to cover the requirements of all lubricants in that class, even with respect to the one item of viscosity—and to expect the oil meeting this specification to lubricate all engines efficiently—is as unreasonable as to expect a fixed size of collar to fit the necks of all men weighing 150 pounds. This proposition becomes obvious when the lubricating-oil requirements of a variety of engine bearings are analyzed. Equally unreasonable is the specification built up by piecing together the highly desirable properties of finished lubricating oils from crude oils of a paraffin base, with the low cold tests and high viscosities of distillate oils from the asphaltic—or from the naphthenic—base crude oils. Likewise it does not seem good business to insist on, and pay the higher manufacturing cost for, oil of a very pale color, if the color of the oil will be impaired immediately upon application to a bearing. The same may be said of any other property which has but a temporary, and perhaps a questionable value. On the other hand, emphasis must be placed on the specifications which insure the successful functioning of the lubricant, for example, resistance to emulsification, cold test, and the combination of high viscosity and resistance to destruction by heat. These are commonly the most difficult specifications to meet unless free rein is given to the manu-

facturer to use suitable raw materials. The refiner must not be limited in his choice of crudes by arbitrary and unnecessary specifications.

The five commones physical tests for lubricating oils are gravity (specific or Baumé gravity), flash (and fire) test, viscosity, cold (pour or cloud) test, and color. The practical significance of each of these properties, excepting gravity, has been discussed previously. Gravity has little importance in lubrication: a heavy oil equal in viscosity and capillarity to a light oil may feed from a sight feeder cup a little faster; gravity assists in distinguishing the crude oil from which the lubricant was made; gravity may assist the shipper in determining the volumetric contents of a barrel or other package, by the weight method of measurement; and gravity, added to a specification, may assist in " fixing " the character of the oil desired, but the real lubricating significance of gravity does not appear. Therefore, the value of its use in a specification is questionable.

A given crude oil may be handled by the refiner in different ways, so that by using two methods it is possible to produce two lubricating oils of the same viscosity which will differ in all other respects. Generally speaking, however, for each variety of crude oil, refiners have found one method which is most suitable for the economical production of the highest grade of finished oils which can be made from that crude.

Starting with several distinct types of crudes and refining by the method best suited to each particular type, the refiner may conduct distillation and all subsequent refining processes with a view to the production of similar, or nearly similar, oils from different crudes. It has been found that if such oils are alike in any one property their other properties will be at variance. This is not true of color; the refiner has such control over this property that he can ordinarily make all oils alike in color.

If, for example, the viscosities are made the same, the gravities, flashes and cold tests will be different; if the flashes coincide, the gravities, viscosities and cold tests will vary. Paraffin-base oils will be characterized by their high flash tests (low volatility) and high Baumé gravities, naphthene-base oils by their low Baumé gravities and low cold tests; asphaltic-base oils will give heavy gravities, low flashes and medium cold tests; and the so-called mixed-base crude oils will produce lubricants whose properties will be combinations of those previously mentioned. Obviously, since the physical properties of a lubricant depend on its chemical constituents, the latter will be different for the several finished lubricants. These chemical differences take on considerable significance when oils are to be used again and again, perhaps at elevated temperatures and in the presence of air and water, and when a long life is expected of them.

The table which follows is given for the purpose of illustrating the differences between the several physical properties of oils from different sources, and to present the characteristics of some typical oils employed successfully for specific purposes.

Lubricating Oil Characteristics

Use	Crude (Base)	Gravity, ° Bé.	Flash, ° F.	Viscosity, Saybolt Universal	Pour, ° F.	Cloud ° F,
Spindle oils	Paraffin	32.5	355	90	..	32
	Paraffin	31.0	385	133	..	32
	American naphthene	22.5	305	100	..	−0
	Mixed	28.0	345	93	..	30
	Mixed	27.5	365	105	..	32
Engine and machine oils	Paraffin	31.0	390	140	28	
	Paraffin	30.5	420	200	28	
	Paraffin	28.5	430	280	26	
	Paraffin	28.8	430	256	45	
	American naphthene	21.0	315	150	0	
	American naphthene	20.5	325	200	0	
	American naphthene	19.0	350	330	0	
	American naphthene	18.5	360	490	5	
	Mixed	26.0	385	145		
	Mixed	25.0	390	206	31	
	Mixed	24.9	405	260	32	
	Mixed	23.5	425	370	40	
	Russian naphthene	29.1	340	72	18	
	Russian naphthene	26.1	347	170	2	
	Russian naphthene	24.4	390	440	6	
	Russian naphthene	23.7	410	800	..	
Turbine oils	Paraffin	29.5	380	140	..	34
	Paraffin	28.5	415	205	..	32
	Paraffin	27.6	430	280	..	30
	Mixed	27.0	385	140	38	
	Mixed	23.0	385	255	45	
	Mixed	24.0	400	315	50	
Automobile oils	Paraffin	31.0	390	161	38	
	Paraffin	30.1	420	200	34	
	Paraffin	30.8	420	218	34	
	Paraffin	28.3	435	275	25	
	American naphthene	22.3	325	137	0	
	American naphthene	20.8	330	230	0	
	American naphthene	20.0	360	328	0	
	Mixed	24.6	395	221	6	
	Mixed	25.4	385	300	35	
Refrigeration machinery oils	Mixed	28.0	360	104	0	
	Mixed	26.0	380	155	0	
	American naphthene	22.5	300	105	0	

References

Rennie's Experiments. Philosophical Transactions, Royal Society, p. 143, 1829.

Conclusions on Friction of Lubricated Surfaces. R. H. Thurston, Jour. Franklin Institute, November, 1878.

Report on Friction Experiments, Beauchamp Tower, 1. Proc. Inst. Mech. Eng., 1883, p. 632; 2. Proc. Inst. Mech. Eng., 1885, p. 64.

Theory of the Sliding Friction of Rotation. R. H. Thurston, Trans. A. S. M. E., Vol. 6, p. 122, 1884.

Laws of Friction of Well Lubricated Journals. John Goodman, Trans. Inst. Civil Eng., 1886.

On Viscosimetry. B. Redwood, Jour. Soc. Chem. Ind., p. 121, 1886.

Viscosity Measurements. Thorpe and Rodger, Philosophical Transactions, Royal Society, 1886. Vol. 185, A. p. 397.

Poiseuille Formula for Viscosity. Jour. Soc. Chem. Ind., 1886.

Theory of Lubrication. Osborne Reynolds, Philosophical Transactions, Royal Society, 1886. Vol. 40, p. 191.

Laws of Unlubricated Friction. A. M. Wellington, Eng. News, April 7, 1888.

Allowable Pressure on Bearing Surfaces. Proc. Inst., Mech. Eng., Jan., 1884, 1885.

Friction of Engines. R. H. Thurston, Trans. A. S. M. E., Vols. 8, 9, 10.

Analysis of Morin's Work on Friction. Prof. J. E. Denton, American Machinist, October 23, 1890. Trans. A. S. M. E., Vol. X, p. 518, 1890.

Capillarity. Lord Raleigh, Phil. Mag., (5) 30, p. 286; p. 386, 1890.

Theory of Surface Forces. Lord Raleigh, Phila. Mag., p. 463, Dec., 1890.

Viscosity. L. R. Wilberforce, Phil. Mag. (5), Vol. 31, p. 407, 1891.

Durability of Oils. Prof. J. E. Denton, Trans. A. S. M. E., Vol. 40.

On the Flow of Viscous Liquids in Two Directions. Lord Raleigh, Phil. Mag., Vol. 36, 1893.

Surface Tension, Proctor Hall, Phil. Mag., Vol. 36, p. 385, November, 1893.

Testing Machines:

- Martin's, Engineering, July 13, 1894.
- Goodman's, Improved Engine, Patent, No. 22,295 of 1895.
- Kingsbury's, Trans. A. S. M. E., Vol. 24, 1903.
- Lahmeyer's, Hodgson Elec. Engr., Vol. 35, p. 585.
- Hopp's, Engineering, Vol. 82, p. 594.
- Hess', Trans. A. S. M. E., Vol. 30, p. 331, 1908.
- Alexander's, Engineer, Vol. 108, p. 291.
- Stribeck, Zeit. Vereines Deutsche Ingeneure, Vol. 45, p. 122, 1901; Vol. 46, p. 1341, 1902.
- Dittmar's, Electrotechnische Zeitschrift, 1899, p. 203; 1902, p. 741.
- Deriban, Sci. Am. Supp. 68:44, July 17, 1909.
- Woodbury's, Trans. A. S. M. E., Vol. 6, Nov., 1884.

Dissertation on Viscosity. Osborne Reynolds, Philosophical Trans., p. 123, 1895.

Friction Horse Power in Factories. C. H. Benjamin, Trans. A. S. M. E., Vol. 18, pp. 228–35.

Surface Tension. Linebarger, Jour. Am. Chem. Soc., Vol. 20, p. 128, 1898; Vol. 21, p. 5, 411, 514, 1899.

Theoretical and Experimental Study of the Internal Friction of Lubricants. N. Petroff. Rev. de Mécanique, Nov., 1900.

Force Feed Lubricators. J. F. Hobart, Am. Electrician, August, 1902.

Resistance of Oil Films. Kennelly and Adams., Elec. World & Engineer, Feb. 7, 1903.

Maximum Load to Break Oil Film. H. F. Moore, Am. Mach., Sept. 24, 1903.
Friction of High Speed Journals. (Trans.) Lasche, Eng. Mag., Vol. 24, p. 915, Mar., 1903.
Bearing Metals. Clamer, Jour. Franklin Inst., July and Oct., 1903.
Allowable Pressure on Bearings. J. T. Nicholson, Am. Mach., Jan. 16, 1908. F. W. Taylor, Trans. A. S. M. E., 1905.
Bearing Pressures for Heavy Intermittent Loads. Oberlin Smith, Trans. A. S. M. E., 1905.
Surface Tension of Mineral Lubricating Oils. Richardson and Hansen. Jour. Soc. Chem. Ind., Vol. 24, p. 315, 1905.
Testing Large Shaft Bearings by Electrical Method. Albert Kingsbury, Trans. A. S. M. E., Vol. 27, 1905.
Steam Cylinder Lubrication. Carpenter, Power, Vol. 25, p. 36, Jan., 1905.
Clearance between Journals and Bearings. John W. Upp, Trans. A. S. M. E., 1905.
Frictional Characteristics of Bearing Metals and Their Relation to Microstructure, M. Price, Eng. Mag., Vol. 29, p. 592, July, 1905.
The Purification of Waste Lubricating Oil. F. H. Davies, Elec. Engr. (London) Jan. 13, 1905.
Oil Economy. A. M. Mattice, Trans. A. S. M. E., Vol. 27, p. 469.
Friction of Metals under Steam Pressure. G. H. Babcock, Trans. A. S. M. E., 1905.
The Lubrication of Steam Engines and Machinery. (Serial) Mech. Engr., Feb. 25, 1905.
Special Oil Grooves. U. S. Patents, No. 941, 925, Nov. 30, 1909.
Bearings. Davis, Elec. World, Feb. 2, 1907.
Properties and Uses of Mineral Lubricating Oils. Walker, Engineering Mag., Vol. 33, p. 455, June, 1907.
Friction and Lubrication. Dr. J. T. Nicholson, Mech. World, Nov. 29, 1907.
Influence of Friction in Economics. Science, Jan. 17, 1908. Vol. 27 (New Series).
Viscosity and Lubrication. Mabery and Matthews, Jour. Am. Chem. Soc., Vol. 30, p. 992, April 7, 1908.
Friction and Bearing Pressures of Journals. W. H. Scott, Mech. World, Oct. 23, 1908.
The Chemical and Physical Testing of Lubricants. J. J. Morgan, Pract. Engr. (London), March 30, 1908.
Experiments on Lubrication. Pullen and Finley, Jour. Inst. Mech. Engr., May, 1909, p. 493.
Lubricants for Cylinders. John M. Sewell, Power, Feb. 9, 1909.
Testing Oil For Steam Turbines. Robt. Job, Trans. A. S. T. M., 1909.
Grease Lubricants. Power, Nov. 9, 1909.
The Mechanical Viscosity of Fluids. T. E. Stanton, Proc. Royal Soc. (2) Vol. 85, pp. 366–76.
The Technical Selection of Railroad Oils as Applied to Cost Reduction. A. D. Smith, Proc. Ry. Club of Pittsburgh, Sept. 24, 1909.
Hydrocarbon Oils and Their Value as Lubricants. A. L. Campbell, Eng. Mag., Vol. 36, p. 469.
Heating By Friction. Sci. Am. Supp., 68:303, November 6, 1909.
Lubrication and Lubricants. C. F. Mabery, Jour. Ind. and Eng. Chem., Vol. 2, No. 4., p. 115, April, 1910.
Circulating Oil System of Lubrication for Steam Turbines. Elec. World, Feb. 13, 1915.
Circulating Oil System of Lubrication. Electrical World, Feb. 13, 1915.
Oil Dripping and Oil Slinging. H. Berry, Am. Mech., Vol. 27, No. 32.
Testing Lubricating Oils. A. H. Gill, Power, April 13, 1915.
Lubrication of Ball Bearings. A. V. Farr, Elec. World, 65:925, April 10, 1915.
Tests of Lubricants. F. M. Baxter, Ry. Age (Mech. Ed.), May, 1915.

Friction and Lubrication. J. T. Nicholson (Serial) Am. Mech., Vol. 31, p. 46,

Motor Cylinder Lubrication. Lieut. G. S. Bryan, Jour. A. S. Nav. Engrs., May, 1915.

Design of an Absolute Viscosimeter for Engineering Tests of Oils. G. B. Upton, Sibley Jour., May, 1915.

The Laws of Lubrication of Journal Bearings. M. D. Hershey, Paper No. 1483, Buffalo Meeting, A. S. M. E., June, 1915.

The Theory of Lubrication. Engineering, p. 103, Aug. 6, 1915, p. 154, August 13, 1915.

The Theory of the Torsion and Rolling Ball Viscosimeters and their Use in Measuring the Effect of Pressure on Viscosity. M. D. Hershey, Jour. Wash. Acad. of Science, September 16, 1916.

"Lubrication and Lubricants." Archbutt and Deeley, Charles Griffin & Co., Ltd., London.

"Bearings." L. P. Alford. McGraw-Hill Book Co., N. Y.

Report on Lubrication by the Advisory Council of the British Dept. of Scientific and Industrial Research.

Lubrication Engineers' Handbook. J. R. Battle. J. B. Lippincott, Philadelphia, Pa.

The Practice of Lubrication. T. C. Thomsen. McGraw-Hill Book Co., New York.

Friction and Lost Work. R. H. Thurston. John Wiley & Sons, New York.

Comparison of Lubricating Greases. H. W. Gillett, Power, November 8, 1910.

Cylinder Lubrication. J. H. Spoor, Power, January 4, 1911.

Lubrication of Marine Engines. J. Veitch Wilson, Mech. Engr., April 28, 1911.

Friction and Lubrication. G. J. Meyers, Jour. A. S. Nav. Engrs., May, 1911.

Lubrication of Ball Bearings. V. W. Pagé, Am. Mech., June 8, 1911.

Efficiency of Lubricating Oils. Sibley, Power, Vol. 31, p. 902.

Frictional Losses in Gas Engines. Engineering, Vol. 82, p. 60.

Tests of Lubricating Greases. G. M. Lewis, Am. Mech., August 24, 1911.

Control Engine Room Oiling System. Power, August 29, 1911.

A Practical Power Plant Oiling System. F. S. Bunker, Power, Oct. 31, 1911.

Soapy Water Lubrication for Air Cylinders. J. B. Roberts, Mech. Engr., Aug. 4, 1911.

Explosion in Air Receiver Due to Oil. Mech. Eng., August 16, 1912.

Methods and Apparatus Used in Petroleum Testing; II, Viscosity. Jour. Soc. Chem. Ind., Vol. 32, p. 543.

Examination of Lubricating Oils for the Cylinders of Steam Engines. A. Cormorant. Jour. Soc. Chem. Ind. Vol. 32, p. 543.

Apparatus for Examination and Study of Behavior of Valve and Cylinder Oils in Saturated and Superheated Steam, etc. P. H. Conradson, Chem. Eng., November, 1912.

Purchase of Lubricating Oil by Specification. A. D. Smith, Prac. Engineer's Soc. of W. Pa., Vol. 28, November, 1912.

Testing and Judging of Steam Turbine Oils. F. Schwartz and J. Marcusson. Z. Angew. Chemie, Vol. 26, p. 385.

Apparatus for the Study of the Behavior of Cylinder Oils in Saturated and Superheated Steam and in Gases. P. H. Conradson, Chem. Eng., November, 1912.

The Determination of the Viscosity of Liquid Lubricants. Holde, Eighth Int. Congress, Applied Chem. Appendix, 25:677–81.

The Theory of Lubrication. L. Ubbelohde, Petroleum Review, Vol. 27, p. 293, p. 325.

Nugent Pressure Returning Oil System. Power, January 19, 1915.

Reports on Switch and Transformer Oils. W. P. Digby, Jour. Inst. E. E., Jan. 1, 1915; also Elec. World, Feb. 6, 1915.

Lubrication of Car Journals. W. A. Clark, Ry. Age. (Mech. Ed.), January, 1915.

PIPE STANDARDS AND USE OF PIPE

BY

F. N. SPELLER

INTRODUCTION

Pipe and tubing for oil production and transportation have been highly developed for the uses to which they are put in the field, with modifications from time to time to meet special requirements. Deep drilling and new developments, particularly the rotary drilling process, have made a demand on engineers and manufacturers for stronger and better pipe and pipe joints. As the operators in certain localities are often obliged to work nearly to the strength of the material, this should be of the very best quality and should be subjected to the most careful inspection and tests that are practicable.

Materials.—Thirty-five years ago wrought iron was the only material available for pipe. As the tensile strength of wrought iron does not average over 46,000 pounds and apparently cannot be increased, it was necessary to get a stronger metal which would still be sufficiently tough and ductile, and for this reason steel came into use. Welded steel pipe is made of low carbon Bessemer or open-hearth steel usually with the following chemical and physical properties.

Physical and Chemical Properties of Steel Pipe

	Bessemer,	Open-hearth,
	Per cent	Per cent
Carbon	not over 0.09	not over 0.15
Manganese	0.30 to 0.60	0.30 to 0.60
Phosphorus	not over 0.10	not over 0.04
Sulphur	not over 0.06	not over 0.05
Tensile strength	not under 50,000 lbs. per sq. in.	not under 45,000 lbs. per sq. in.
Yield point	not under 30,000 lbs. per sq. in.	not under 25,000 lbs. per sq. in.
Elongation	not under 20% in 8 in.	not under 22% in 8 in.

Seamless steel pipe has more recently come into general use for drill pipe and other special purposes, especially where the ends are upset. A higher carbon open-hearth steel may be used in this process which has considerable advantage in offering greater strength and resistance to shock. The 0.30 to 0.40 carbon steel usually used for seamless drill pipe will give the following physical properties.

Physical Properties of 0.30 to 0.40 Carbon Steel Seamless Drill Pipe

	Minimum	Average
Tensile strength	67,500 pounds	75,000 pounds
Yield point	37,000 pounds	45,000 pounds
Elongation in 2 inches	28 per cent	35.0 per cent
Reduction in area	30 per cent	37.5 per cent

Couplings are made of welded wrought iron or steel, or seamless steel.

Welding and annealing.—Good welding quality is of prime importance in pipe steel, both for the purpose of sound welding of the seam in the mill and the welding requirements of users of pipe and boiler tubes. Careful selection of materials and their combination and treatment under the supervision of metallurgical and other technical experts assures this quality in modern wrought tubular products. A system of tests and inspections is maintained to further safeguard the results obtained.

Welding as applied in the manufacture of modern tubular products is a highly developed art in this country. The welding heat naturally produces a larger grain in the metal. This does not necessarily mean loss of ductility, but, where a large margin of safety against failure by shock is desired, the grain may be refined by annealing. The method giving best results is to heat the steel to a bright orange color in shop light (1750° F.) for a few minutes, allowing the piece to cool in the air. Very slow cooling is not necessary. So treated, the fracture of the metal should show a fine silky texture without any trace of crystallization.

Where the object of annealing is only to remove strain in the metal, heating to a temperature of about 1300° F. will be sufficient, followed by slow and uniform cooling without coming in contact with anything that would hasten the cooling locally. The welding quality of modern tubular products is obtained by special attention in the manufacture of the steel itself, in connection with which uniformity is considered to be one of the main considerations. To accomplish this the leading manufacturers find it desirable to make pipe steel directly from the ore to the finished product with close attention to each operation and with this object continually in view.

Processes of Manufacture of Welded Pipe and Tubes

Lap-weld process.—The "skelp" or plate used in making lap-welded pipe is rolled to the necessary width and gage for the size of pipe to be made, the edges being scarfed and overlapped when the skelp is bent into shape, thus giving a comparatively large welding surface, compared with the thickness of the plate (see Fig. 1).

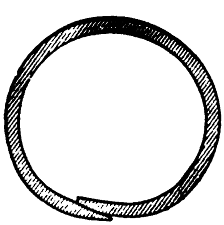


Fig. 1.—Lap weld.

The skelp is first heated to redness in a "bending furnace," and then drawn from the front of the furnace through a die, the inside of which gradually assumes a circular shape, so that the skelp when drawn through is bent into the form of a tube with the edges overlapping as shown in Fig. 1. For the larger sizes of pipe where the skelp is of heavier proportions the hot skelp is run through a set of bending rolls to form the rough tube, instead of being drawn through a bending die. In the next operation the skelp so formed is heated evenly to the welding temperature

in a regenerative furnace. When the proper temperature is obtained, the skelp is pushed through an opening in the front of this furnace into the welding rolls, passing between two rolls set one above the other, each having a semicircular groove, so that the two together form a circular pass. Between these rolls a mandrel is held in position inside the pipe, the lapped edges of the skelp being firmly pressed together at a welding heat between the mandrel and the rolls. The pipe then enters a similarly shaped set of rolls to correct any irregularities and to give the outside diameter required. It will be noted that the outside diameter is fixed by these rolls; any variation in gage, therefore, makes a proportional variation in the internal diameter. (This also applies to butt-weld pipe.) Finally, the pipe is passed to the straightening, or cross rolls, consisting of two rolls set with their axes askew. The surfaces of these rolls are so curved that the pipe is in contact with each for nearly the whole length of the roll, and is passed forward and rapidly rotated when the rolls are revolved. The pipe is made practically straight by the cross rolls, and is also given a clean finish, with a firmly adhering film of blue oxide.

After this last operation the pipe is rolled up an inclined cooling table, so that the metal will cool off slowly and uniformly without internal strain. When cool enough, the rough ends are removed by cold saws or in a cutting-off machine, after which the pipe is ready for inspection and testing.

In the case of some sizes of double-extra-strong pipe (3 inches to 8 inches) made by the lap-weld process, the pipes are first made to such sizes as will telescope one within the other, the respective welds being placed opposite each other; these are then returned to the furnace, brought to the proper heat, and given a pass through the welding rolls. While a pipe made in this way is, in respect to its resistance to internal pressure, as strong as or stronger than pipe made from one piece of skelp, it is not necessarily welded at all points between the two tubular surfaces; however, each piece is first thoroughly welded at the seam before telescoping.

Butt-weld process.—Skelp used in making butt-welded pipe comes from the rolling department of the steel mills with a specified length, width, and gage, according to the size of pipe into which it will be made. The edges are slightly beveled with the face of the skelp, so that the surface of the plate which is to become the inside of the pipe is not quite as wide as that which forms the outside; thus when the edges are brought together they meet squarely, as indicated in Fig. 2. One end of the skelp has been trimmed to a V shape for a short distance and slightly turned up to facilitate the grip of the welding tongs.

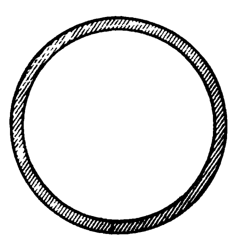


FIG. 2.—Butt weld.

The skelp is then heated uniformly to the welding temperature, in furnaces similar in general construction to those used in lap-welding. When properly heated the pointed ends of the skelp are gripped by heavy tongs and drawn from the furnaces through funnel shaped dies or bells. The inside of the welding bell is so shaped that the plate is gradually turned around into the shape of a tube, the edges being forced squarely together and welded. For some sizes of pipe the skelp is drawn through two bells consecutively at one heat, one bell being just behind the other, the second one being of smaller diameter than the first.

After the skelp has been welded into pipe, it passes through a set of sizing rolls, where it is reduced slightly in size and elongated. From the sizing rolls, the pipe passes across a cooling table to another set of specially designed rolls which again slightly reduce the size and elongate the pipe, and give it the correct finished diameter and circular contour. Any heavy mill scale, or welding-scale, which may be present is

removed by this rolling operation, leaving the pipe wall smooth and clean.[1] The pipe then passes across a cooling table and then to the cross rolls where any necessary straightening is done, and then to a tank of water where any loose scale is washed out; for certain sizes the loose scale is blown out by a blast of compressed air. From this point on, butt-weld pipe is handled in much the same manner as lap-weld—namely, the rough ends are removed, each length is inspected and tested, and the pipe is then ready for threading and hydrostatic testing. Each length of pipe is given the hydrostatic pressure test.

In making double-extra-strong pipe by the butt-weld process, the pull required is so great that it is found necessary to weld a strong bar on the end of the skelp, thereby more evenly distributing the strain. With this bar the skelp is drawn through several welding bells of decreasing size, and is reheated between each draw until the seam is thoroughly welded.

Seamless pipe.—Seamless pipe is made from open-hearth steel only, as this material has been found to have the properties best adapted to the severity of the operations used in manufacture. The blooms are rolled down to billets, each of which has just enough material for making one length of pipe. The billets are known as "rounds," being round in shape, instead of square as required for welded pipe. These billets are heated and pierced from end to end after being indented on the center of one end for about 1 inch in a hydraulic punching machine.

Cold "rounds" are taken from the stock yard and fed into the rear of a heating furnace. The bed of this furnace is sloped, so that the "rounds" roll by gravity to the forward end. Having reached the proper temperature for piercing during their passage through the furnace, they are withdrawn by long tongs and are then pushed, centered end foremost, into the piercing mill. Here they are caught by rolls which are so angularly disposed as to catch hold of the "round," rotate it, and force it forward over a pointed mandrel which is held stationary near the center of the space between the rolls. The "round" or billet is thus pierced through its entire length. At this stage the pipe is rather rough and thick, but without seam or weld.

To obtain the required diameter, wall-thickness and length, the rough pipe is rolled between grooved rolls of the size required, and over another mandrel corresponding in size to the inside diameter of pipe required. The wall-thickness is usually reduced in this operation, the length increased, and the approximate size obtained. While still at working temperature, the pipe passes on through a reeling machine where any mill scale is removed. The pipe is given a smooth surface, and the outside diameter corrected to some extent. From this machine, the pipe passes to the sizing or finishing rolls, which give the exact outside diameter required.

After the pipe has cooled on a continuously traveling table, the rough ends are removed, the pipe is straightened, inspected, and subjected to an internal hydrostatic pressure test, the pressure varying with the size of pipe and the service intended.

The pipe is fitted with threads and couplings or such other types of joints as may be required. Seamless pipe for drilling purposes may require special operations in manufacture, such as the upsetting of the ends to make a joint that will be dependable under unusually severe service conditions.

Hammer-weld process.—The process of making lap-weld pipe by hammer welding is relatively new, as compared to the butt-weld process and the lap-weld process of making pipe, and the sizes made are relatively large in diameter and proportionately thick in wall. The plates used are of open-hearth steel of such composition as

[1] This scale-removing operation is a recent improvement introduced in all the mills of the National Tube Company. The welding, sizing and straightening operations described are common to all butt welding mills.

to give the best results in welding and other manipulations in manufacture. Upon being received from the plate mill, the plates are inspected and measured, then charged into a plate heating furnace where they are brought to medium red heat for bending and scarfing. Scarfing consists of slightly beveling or rolling down the longitudinal edges of the plate to the extent that they are to overlap, sufficient thickness being allowed in order that the force of the hammer will be most effective in welding them together. (See Fig. 1, under description of lap-weld process.) Plate which are relatively thin are bent cold and not scarfed.

When the plates have been suitably prepared, they are bent into rough tubular form by several long horizontal rolls, in much the same manner as plates are bent for boiler shells and tank construction; however, they are bent completely around, until the edges overlap and the approximate diameter of tube is obtained. The rough tube thus obtained is taken to the welding machine where the overlapped edges are heated to the welding temperature by water-gas blowpipes about a foot long placed opposite to each other—inside and outside of the pipe. After reaching the proper temperature this portion of the seam is hammer-forged on a long anvil after which the next portion is heated and the forging operation repeated until the seam is all welded.

When completely welded, the pipe is placed in an annealing furnace. After reaching the proper temperature it is removed from the furnace and subjected to another rolling operation by which it is straightened and given its proper circular section. The pipes are handled individually between operations by an overhead traveling charging machine. The size of the pipe and its weight require such a method as this.

When the pipe has been welded, annealed and straightened, it is inspected, and the ends are trued up by facing on a lathe-type of trimming machine.

Each length of hammer-welded pipe is subjected to an internal-pressure test. This test is given in a machine where the pipe is first filled with water and then a hydrostatic pressure of from 150 to 2000 pounds per square inch is applied. The test pressure varies according to the size and wall-thickness of the pipe and the service for which it is intended. After the hydrostatic-pressure test the pipe is given a thorough inspection as to surface finish and dimensions.

Hammer-welded pipe can be furnished with several types of joints suitable for different service conditions. It is also furnished with plain ends, or with the ends of the pipe specially prepared to meet any practical requirement for joining end to end as desired by the purchaser. The joints generally employed are of a flanged or expanded type, with or without annular recesses for holding lead or other tamping materials. Plain end pipe of this kind is well adapted for the use of Dresser joints.

When desired, two or more lengths of pipe can be welded end to end, to make 40-foot lengths, which can be tested, and shipped as one length, it being impractical to make this large class of pipe in lengths longer than 30 feet from a single plate.

Hammer-welded pipe is now made in sizes from 24 to 96 inches outside diameter.

Because of the strength and tightness of the weld and the ease with which tight heads can be attached, this pipe is particularly suitable for the construction of gas tight tanks, receivers, stills and other containers.

Weights and Dimensions of Wrought Pipe, Tubing, Casing and Special Drilling Material Used in the Oil Country. (From National Tube Company's Book of Standards and Other of their Publications as Revised up to Dec., 1921).

Standard Pipe—Full Standard Weight—Black and Galvanized

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Threads per inch
	External	Internal		Plain ends	Threads and couplings	
1/8	0.405	0.269	0.068	0.244	0.245	27
1/4	.540	.364	.088	.424	.425	18
3/8	.675	.493	.091	.567	.568	18
1/2	.840	.622	.109	.850	.852	14
3/4	1.050	.824	.113	1.130	1.134	14
1	1.315	1.049	.133	1.678	1.684	11½
1¼	1.660	1.380	.140	2.272	2.281	11½
1½	1.900	1.610	.145	2.717	2.731	11½
2	2.375	2.067	.154	3.652	3.678	11½
2½	2.875	2.469	.203	5.793	5.819	8
3	3.500	3.068	.216	7.575	7.616	8
3½	4.000	3.548	.226	9.109	9.202	8
4	4.500	4.026	.237	10.790	10.889	8
4½	5.000	4.506	.247	12.538	12.642	8
5	5.563	5.047	.258	14.617	14.810	8
6	6.625	6.065	.280	18.974	19.185	8
7	7.625	7.023	.301	23.544	23.769	8
8	8.625	8.071	.277	24.696	25.000	8
8	8.625	7.981	.322	28.554	28.809	8
9	9.625	8.941	.342	33.907	34.188	8
10	10.750	10.192	.279	31.201	32.000	8
10	10.750	10.136	.307	34.240	35.000	8
10	10.750	10.020	.365	40.483	41.132	8
11	11.750	11.000	.375	45.557	46.247	8
12	12.750	12.090	.330	43.773	45.000	8
12	12.750	12.000	.375	49.562	50.706	8
14 O. D.	14.000	13.250	.375	54.568	55.824	8
15 O. D.	15.000	14.250	.375	58.573	60.375	8
16 O. D.	16.000	15.250	.375	62.579	64.500	8

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise ordered.

All weights given in pounds. All dimensions given in inches.

For cut lengths, an extra charge will be made above random lengths.

For pipe smoothed on the inside, known as reamed and drifted, an extra charge will be made above standard pipe.

For galvanized, or coated pipe, an extra charge will be made above black.

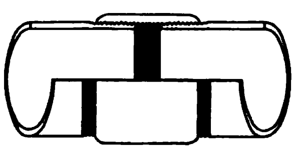


Fig. 3.—Section of standard pipe coupling and joint.

Extra Strong Pipe—Black and Galvanized
All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per foot, plain ends
	External	Internal		
⅛	0.405	0.215	0.095	0.314
¼	.540	.302	.119	.535
⅜	.675	.423	.126	.738
½	.840	.546	.147	1.087
¾	1.050	.742	.154	1.473
1	1.315	.957	.179	2.171
1¼	1.660	1.278	.191	2.996
1½	1.900	1.500	.200	3.631
2	2.375	1.939	.218	5.022
2½	2.875	2.323	.276	7.661
3	3.500	2.900	.300	10.252
3½	4.000	3.364	.318	12.505
4	4.500	3.826	.337	14.983
4½	5.000	4.290	.355	17.611
5	5.563	4.813	.375	20.778
6	6.625	5.761	.432	28.573
7	7.625	6.625	.500	38.048
8	8.625	7.625	.500	43.388
9	9.625	8.625	.500	48.728
10	10.750	9.750	.500	54.735
11	11.750	10.750	.500	60.075
12	12.750	11.750	.500	65.415

The permissible variation in weight is 5 per cent above and 5 per cent below.

Double Extra Strong Pipe—Black and Galvanized
All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per foot, plain ends
	External	Internal		
½	0.840	0.252	0.294	1.714
¾	1.050	.434	.308	2.440
1	1.315	.599	.358	3.659
1¼	1.660	.896	.382	5.214
1½	1.900	1.100	.400	6.408
2	2.375	1.503	.436	9.029
2½	2.875	1.771	.552	13.695
3	3.500	2.300	.600	18.583
3½	4.000	2.728	.636	22.850
4	4.500	3.152	.674	27.541
4½	5.000	3.580	.710	32.530
5	5.563	4.063	.750	38.552
6	6.625	4.897	.864	53.160
7	7.625	5.875	.875	64.079
8	8.625	6.875	.875	72.424

The permissible variation in weight is 10 per cent above and 10 per cent below. The following notes apply to both extra strong and double extra strong pipe tables: Furnished with plain ends and in random lengths, unless otherwise ordered. All weights given in pounds. All dimensions given in inches. Random lengths of extra strong and double extra strong pipe are considered to be 12 feet to 22 feet, the maker has the privilege, however, of supplying not exceeding 5 per cent of total order in lengths from 6 feet to 12 feet. For pipe fitted with threads and couplings, an extra charge will be made above plain ends. For cut lengths, an extra charge will be made above random lengths. For galvanized, or coated pipe, an extra charge will be made above black.

"National" Line Pipe

All weights and dimensions are nominal

Size	Diameters		Thick-ness	Weight per Foot		Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings		Diam-eter	Length	Weight
1/8	0.405	0.269	0.068	0.244	0.246	27	0.582	1 1/8	0.043
1/4	0.540	0.364	.088	0.424	0.426	18	0.724	1 3/8	0.069
3/8	0.675	0.493	.091	0.567	0.571	18	0.898	1 5/8	0.126
1/2	0.840	0.622	.109	0.850	0.856	14	1.085	1 7/8	0.205
3/4	1.050	0.824	.113	1.130	1.138	14	1.316	2 1/8	0.316
1	1.315	1.049	.133	1.678	1.688	11 1/2	1.575	2 3/8	0.445
1 1/4	1.660	1.380	.140	2.272	2.300	11 1/2	2.054	2 7/8	0.974
1 1/2	1.900	1.610	.145	2.717	2.748	11 1/2	2.294	2 7/8	1.103
2	2.375	2.067	.154	3.652	3.716	11 1/2	2.841	3 5/8	2.146
2 1/2	2.875	2.469	.203	5.793	5.881	8	3.389	4 1/8	3.387
3	3.500	3.068	.216	7.575	7.675	8	4.014	4 1/8	4.076
3 1/2	4.000	3.548	.226	9.109	9.261	8	4.628	4 1/8	5.510
4	4.500	4.026	.237	10.790	10.980	8	5.233	4 1/8	6.673
4 1/2	5.000	4.506	.247	12.538	12.742	8	5.733	4 1/8	7.379
5	5.563	5.047	.258	14.617	14.966	8	6.420	5 1/8	11.730
6	6.625	6.065	.280	18.974	19.367	8	7.482	5 1/8	13.869
7	7.625	7.023	.301	23.544	23.975	8	8.482	5 1/8	15.883
8	8.625	8.071	.277	24.696	25.414	8	9.596	6 1/8	24.130
8	8.625	7.981	.322	28.554	29.213	8	9.596	6 1/8	24.130
9	9.625	8.941	.342	33.907	34.612	8	10.596	6 1/8	26.838
10	10.750	10.192	.279	31.201	32.515	8	11.958	6 5/8	39.772
10	10.750	10.136	.307	34.240	35.504	8	11.958	6 5/8	39.772
10	10.750	10.020	.365	40.483	41.644	8	11.958	6 5/8	39.772
11	11.750	11.000	.375	45.557	46.805	8	12.958	6 5/8	43.326
12	12.750	12.090	.330	43.773	45.217	8	13.958	6 5/8	46.898
12	12.750	12.000	.375	49.562	50.916	8	13.958	6 5/8	46.898
14 O.D.	14.000	13.250	.375	54.568	56.649	8	15.446	7 1/8	65.506
15 O.D.	15.000	14.250	.375	58.573	60.802	8	16.446	7 1/8	70.031
16 O.D.	16.000	15.250	.375	62.579	64.955	8	17.446	7 1/8	74.555

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise ordered.

Taper of threads is 3/4 inch diameter per foot length for all sizes.

The weight per foot of pipe with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet. All weights given in pounds. All dimensions given in inches.

On sizes made in more than one weight, weight desired must be specified.

Boston Casing

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Threads per inch	Couplings			Test pressure in pounds
	External	Internal		Plain ends	Threads and couplings		Diameter	Length	Weight	
2	2.250	2.050	0.100	2.296	2.340	14	2.714	2⅝	1.361	750
2¼	2.500	2.284	.108	2.759	2.820	14	2.964	2⅝	1.499	750
2½	2.750	2.524	.113	3.182	3.250	14	3.214	2⅞	1.804	750
2¾	3.000	2.768	.116	3.572	3.650	14	3.464	2⅞	1.957	750
3	3.250	3.010	.120	4.011	4.100	14	3.771	3⅛	2.612	750
3¼	3.500	3.250	.125	4.505	4.600	14	4.021	3⅛	2.799	750
3½	3.750	3.492	.129	4.988	5.100	14	4.271	3⅛	2.987	750
3¾	4.000	3.732	.134	5.532	5.650	14	4.521	3⅛	3.174	750
4	4.250	3.974	.138	6.060	6.200	14	4.771	3⅝	3.923	750
4¼	4.500	4.216	.142	6.609	6.750	14	5.021	3⅝	4.141	750
4¼	4.500	4.090	.205	9.403	9.500	14	5.021	3⅝	4.141	900
4½	4.750	4.460	.145	7.131	7.250	14	5.271	3⅝	4.360	750
4½	4.750	4.364	.193	9.393	9.500	14	5.271	3⅝	4.360	900
4¾	5.000	4.696	.152	7.870	8.060	14	5.521	3⅝	4.578	750
5	5.250	4.944	.153	8.328	8.500	14	5.828	4⅛	5.929	750
5	5.250	4.886	.182	9.851	10.000	14	5.828	4⅛	5.929	800
5	5.250	4.886	.182	9.851	10.000	11½	5.800	4⅛	5.742	800
5	5.250	4.768	.241	12.892	13.000	11½	5.800	4⅛	5.742	1000
5	5.250	4.648	.301	15.909	16.000	11½	5.800	4⅛	5.742	1200
5 3/16	5.500	5.192	.154	8.792	9.000	14	6.078	4⅛	6.200	750
5⅝	6.000	5.672	.164	10.222	10.500	14	6.664	4⅛	7.729	750
5⅝	6.000	5.620	.190	11.789	12.000	11½	6.636	4⅛	7.516	800
5⅝	6.000	5.552	.224	13.818	14.000	11½	6.636	4⅛	7.516	900
5⅝	6.000	5.450	.275	16.814	17.000	11½	6.636	4⅛	7.516	1000
6¼	6.625	6.287	.169	11.652	12.000	14	7.308	4⅝	9.825	750
6¼	6.625	6.255	.185	12.724	13.000	14	7.308	4⅝	9.825	800
6⅝	7.000	6.652	.174	12.685	13.000	14	7.692	4⅝	10.497	750
6⅝	7.000	6.538	.231	16.699	17.000	11½	7.664	4⅝	10.225	900
7¼	7.625	7.263	.181	14.390	14.750	14	8.317	4⅝	11.401	750
7⅝	8.000	7.628	.186	15.522	16.000	11½	8.788	5⅛	15.308	750
7⅝	8.060	7.528	.236	19.569	20.000	11½	8.788	5⅛	15.308	800
8¼	8.625	8.249	.188	16.940	17.500	11½	9.413	5⅛	16.461	750
8¼	8.625	8.191	.217	19.486	20.000	11½	9.413	5⅛	16.461	800
8¼	8.625	8.097	.264	23.754	24.000	11½	9.413	5⅛	16.461	800
8⅝	9.000	8.608	.196	18.429	19.000	11½	9.788	5⅛	17.153	750
9⅝	10.000	9.582	.209	21.855	22.750	11½	10.911	6⅛	26.136	750
9⅝	10.000.	9.434	.283	29.369	30.250	11½	10.911	6⅛	26.136	900
10⅝	11.000	10.552	.224	25.780	26.750	11½	11.911	6⅛	28.536	750
11⅝	12.000	11.514	.243	30.512	31.500	11½	12.911	6⅛	31.051	500
12½	13.000	12.482	.259	35.243	36.500	11½	14.025	6⅛	37.499	500
13½	14.000	13.448	.276	40.454	42.000	11½	15.139	6⅛	44.495	500
14½	15.000	14.418	.291	45.714	47.500	11½	16.263	6⅛	52.401	500
15½	16.000	15.396	.302	50.632	52.500	11½	17.263	6⅛	55.779	500

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise specified. Taper of threads is ¾ inch diameter per foot length for all sizes.

Thickness of walls make it impracticable to cut threads of coarser pitch than shown on table. The weight per foot of casing with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet. All weights given in pounds. All dimensions given in inches.

Diamond BX Casing

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings			Diameter	Length	Weight
4½	4.750	4.082	0.334	15.752	16.000	1800	10	5.364	6⅜	9.963
4¾	5.000	4.500	.250	12.682	12.850	1400	10	5.491	6⅝	8.533
4¾	5.000	4.408	.296	14.870	15.000	1700	10	5.491	6⅝	8.533
5⅝	6.000	5.352	.324	19.641	20.000	1500	10	6.765	7½	15.748
6¼	6.625	6.049	.288	19.491	20.000	1400	10	7.390	7⅝	18.559
6¼	6.625	5.921	.352	23.582	24.000	1500	10	7.390	7⅝	18.559
6¼	6.625	5.855	.385	25.658	26.000	1600	10	7.390	7⅝	18.559
6¼	6.625	5.791	.417	27.648	28.000	1700	10	7.390	7⅝	18.559
6⅝	7.000	6.456	.272	19.544	20.000	1200	10	7.698	7⅝	17.943
6⅝	7.000	6.336	.332	23.643	24.000	1300	10	7.698	7⅝	17.943
6⅝	7.000	6.276	.362	25.663	26.000	1400	10	7.698	7⅝	17.943
6⅝	7.000	6.214	.393	27.731	28.000	1500	10	7.698	7⅝	17.943
6⅝	7.000	6.154	.423	29.712	30.000	1600	10	7.698	7⅝	17.943
7⅝	8.000	7.386	.307	25.223	26.000	1200	10	8.888	8½	27.410
8¼	8.625	8.017	.304	27.016	28.000	1000	10	9.627	8½	33.096
8¼	8.625	7.921	.352	31.101	32.000	1100	10	9.627	8½	33.096
8¼	8.625	7.825	.400	35.137	36.000	1200	10	9.627	8½	33.096
8¼	8.625	7.775	.425	37.220	38.000	1300	10	9.627	8½	33.096
8¼	8.625	7.651	.487	42.327	43.000	1500	10	9.627	8½	33.096
9⅝	10.000	9.384	.308	31.881	33.000	1000	10	11.002	8½	38.162
10	10.750	10.054	.348	38.661	40.000	800	10	11.866	8½	45.365
10	10.750	9.960	.395	43.684	45.000	900	10	11.866	8½	45.365
10	10.750	9.902	.424	46.760	48.000	1000	10	11.866	8½	45.365
10	10.750	9.784	.483	52.962	54.000	1200	10	11.866	8½	45.365
11	11.750	11.000	.375	45.557	47.000	900	10	12.866	8½	49.379
11	11.750	10.772	.489	58.811	60.000	1200	10	12.866	8½	49.379
11¾	12.000	11.384	.308	38.460	40.000	800	10	13.116	8½	50.445
12½	13.000	12.438	.281	38.171	40.000	700	10	14.116	8½	54.508
12½	13.000	12.360	.320	43.335	45.000	800	10	14.116	8½	54.508
12½	13.000	12.282	.359	48.467	50.000	900	10	14.116	8½	54.508
12½	13.000	12.220	.390	52.523	54.000	1000	10	14.116	8½	54.508
13½	14.000	13.344	.328	47.894	50.000	800	10	15.151	9½	67.912
15½	16.000	15.198	.401	66.806	70.000	800	10	17.477	9½	98.140

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise specified.

Taper of threads is ¾ inch diameter per foot length for all sizes.

The weight per foot of casing with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.

All weights given in pounds. All dimensions given in inches.

This casing is not made in lighter weights, but can be made heavier than shown above.

When one size of casing is intended to telescope with another, it should always be specified.

South Penn Casing

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings			Diameter	Length	Weight
5 3/16	5.500	5.044	0.228	12.837	13.000	1000	11½	6.050	4¾	6.759
5 3/16	5.500	4.892	.304	16.870	17.000	1200	11½	6.155	5¼	8.849
6¼	6.625	6.257	.184	12.657	13.000	800	11½	7.280	5¼	10.630
6¼	6.625	6.135	.245	16.694	17.000	1000	11½	7.280	5¼	10.630
6¼	6.625	6.041	.292	19.750	20.000	1200	11½	7.280	5¾	11.647
6¼	6.625	5.913	.356	23.835	24.000	1500	11½	7.280	5¾	11.647
6⅝	7.000	6.538	.231	16.699	17.000	900	10	7.642	5¼	11.133
6⅝	7.000	6.450	.275	19.751	20.000	1000	10	7.699	6¼	14.458
6⅝	7.000	6.334	.333	23.711	24.000	1200	10	7.699	6¼	14.458
8¼	8.625	8.097	.264	23.574	24.000	1000	8	9.358	6¼	18.577
8¼	8.625	8.003	.311	27.615	28.000	1200	8	9.358	6¼	18.577
8¼	8.625	7.907	.359	31.693	32.000	1200	8	9.358	6¼	18.577
10	10.750	10.192	.279	31.201	32.515	800	8	11.958	6¾	39.772
10	10.750	10.146	.302	33.699	35.000	900	8	11.958	6¾	39.772
10	10.750	10.050	.350	38.875	40.000	1000	8	11.958	6¾	39.772
12½	13.000	12.356	.322	43.599	45.000	700	8	14.085	7¼	46.464
12½	13.000	12.278	.361	48.730	50.000	800	8	14.085	7¼	46.464

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise specified.

Taper of threads is ¾ inch diameter per foot length for all sizes, except the 8¼ inch, 10 inch, and 12½ inch which are ½ inch taper.

The weight per foot of casing with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.

All weights given in pounds.

All dimensions given in inches.

For illustration showing joint, see Fig. 4.

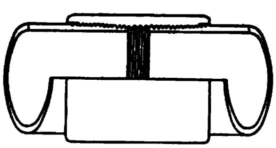


FIG. 4.—Section of South Penn casing coupling and joint.

Boston Casing—Inserted Joint

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per foot plain ends	Threads per inch	Joint		Test pressure in pounds
	External	Internal				Length of joint —"L"	Diameter of joint —"D"	
2	2.250	2.050	0.100	2.296	14	0.967	2.340	750
2¼	2.500	2.284	.108	2.759	14	.992	2.606	750
2½	2.750	2.524	.113	3.182	14	1.017	2.866	750
2¾	3.000	2.768	.116	3.572	14	1.042	3.122	750
3	3.250	3.010	.120	4.011	14	1.067	3.380	750
3¼	3.500	3.250	.125	4.505	14	1.092	3.640	750
3½	3.750	3.492	.129	4.988	14	1.117	3.898	750
3¾	4.000	3.732	.134	5.532	14	1.142	4.158	750
4	4.250	3.974	.138	6.060	14	1.167	4.416	750
4¼	4.500	4.216	.142	6.609	14	1.192	4.674	750
4½	4.750	4.460	.145	7.131	14	1.217	4.930	750
4¾	5.000	4.696	.152	7.870	14	1.242	5.194	750
5	5.250	4.944	.153	8.328	14	1.267	5.446	750
5 3/16	5.500	5.192	.154	8.792	14	1.292	5.698	750
5⅝	6.000	5.672	.164	10.222	14	1.342	6.218	750
6¼	6.625	6.287	.169	11.652	14	1.405	6.853	750
6⅝	7.000	6.652	.174	12.685	14	1.442	7.238	750
7¼	7.625	7.263	.181	14.390	14	1.505	7.877	750
7⅝	8.000	7.628	.186	15.522	11½	1.573	8.238	750
8¼	8.625	8.249	.188	16.940	11½	1.636	8.867	750
8⅝	9.000	8.608	.196	18.429	11½	1.673	9.258	750
9⅝	10.000	9.582	.209	21.855	11½	1.773	10.284	750
10⅝	11.000	10.552	.224	25.780	11½	1.873	11.314	750
11⅝	12.000	11.514	.243	30.512	11½	1.973	12.352	500
12½	13.000	12.482	.259	35.243	11½	2.073	13.384	500
13½	14.000	13.448	.276	40.454	11½	2.173	14.418	500
14½	15.000	14.418	.291	45.714	11½	2.273	15.448	500
15½	16.000	15.396	.302	50.632	11½	2.373	16.470	500

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished in random lengths unless otherwise specified.

Regular taper of threads is ¾ inch diameter per foot length for all sizes, but maker will furnish ¼ inch, ½ inch, or ⅝ inch taper if so specified.

All weights given in pounds. All dimensions given in inches.

On sizes made in more than one weight or thread, weight and number of threads desired must be specified.

Thickness of walls makes it impracticable to cut threads of coarser pitch than shown on table.

For illustration showing joint, see Fig. 5.

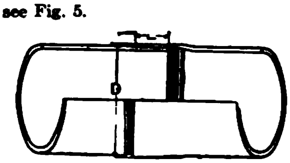


FIG. 5.—Section of Boston casing—inserted joint.

Flush-joint Tubing

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per foot, plain ends	Test pressure in pounds per inch	Joints	
	External	Internal				Threads per inch	Length of joint "L"
3	3.500	3.068	0.216	7.575	1000	14	1¾
3½	4.000	3.548	.226	9.109	1000	14	1¾
4	4.500	4.026	.237	10.790	1000	11½	1¾
4½	5.000	4.506	.247	12.538	1000	11½	1¾
5	5.563	5.047	.258	14.617	1000	11½	2
	6.000	5.440	.280	17.105	1000	11½	2
6	6.625	6.065	.280	18.974	1000	11½	2
	7.000	6.398	.301	21.535	1000	11½	2
7	7.625	7.023	.301	23.544	1000	11½	2
	8.000	7.356	.322	26.404	1000	10	2
8	8.625	7.981	.322	28.554	1000	10	2
	9.000	8.316	.342	31.624	900	10	2
9	9.625	8.941	.342	33.907	900	10	2
	10.000	9.270	.365	37.559	900	10	2¼
10	10.750	10.020	.365	40.483	900	10	2¼
	12.000	11.250	.375	46.558	800	10	2¼
12	12.750	12.000	.375	49.562	800	10	2¼
14 O. D.	14.000	13.124	.438	63.441	800	8	2½
15 O. D.	15.000	14.124	.438	68.119	750	8	2½
16 O. D.	16.000	15.000	.500	82.771	750	8	2½
17 O. D.	18.000	17.000	.500	93.451	750	8	2½

Test applied on pipe prior to threading.
The permissible variation in weight is 5 per cent above and 5 per cent below.
Furnished in random lengths unless otherwise specified.
Taper of threads is ¾ inch diameter per foot length for all sizes, unless otherwise specified.
Weights lighter than those given in above table are not suitable for flush joints.
All weights given in pounds. All dimensions given in inches.
For illustration showing joint, see Fig. 6.

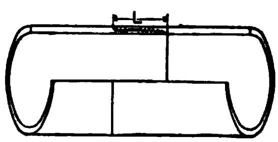


FIG. 6.—Section of flush-joint tubing.

Allison Vanishing-thread Tubing—Ends Upset
All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	O. D. of upset	Couplings		
	External	Internal		Plain ends	Threads and couplings				Diameter	Length	Weight
2	2.375	2.067	0.154	3.652	3.731	1800	11½	2 9/16	3.057	3½	2.484
2½	2.875	2.469	.203	5.793	5.903	2100	8	3 1/16	3.616	4½	3.845
3	3.500	3.068	.216	7.575	7.699	1900	8	3 11/16	4.237	4½	4.557
3½	4.000	3.548	.226	9.109	9.287	1500	8	4 3/16	4.848	4½	6.036
4	4.500	4.026	.237	10.790	10.984	1500	8	4 11/16	5.345	4½	6.768
4½	5.000	4.506	.247	12.538	12.744	1500	8	5 3/16	5.842	4½	7.426
5	5.563	5.047	.258	14.617	14.962	1500	8	5¾	6.509	5½	11.821
6	6.625	6.065	.280	18.974	19.359	1500	8	6¾	7.627	5½	13.931
7	7.625	7.023	.301	23.544	23.957	1200	8	7¾	8.621	5½	15.778
8	8.625	7.981	.322	28.554	29.196	1200	8	8¾	9.729	6½	24.119

Allison Vanishing-thread Tubing—Not Upset
All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings			Diameter	Length	Weight
1¼	1.660	1.380	0.140	2.272	2.303	1200	11½	2.070	2½	1.052
1½	1.900	1.610	.145	2.717	2.751	1700	11½	2.309	2½	1.188
2	2.375	2.067	.154	3.652	3.723	1700	11½	2.870	3½	2.315
2½	2.875	2.469	.203	5.793	5.893	2000	8	3.429	4½	3.625
3	3.500	3.068	.216	7.575	7.689	1800	8	4.050	4½	4.338
3½	4.000	3.548	.226	9.109	9.276	1500	8	4.661	4½	5.782
4	4.500	4.026	.237	10.790	10.973	1500	8	5.158	4½	6.512
4½	5.000	4.506	.247	12.538	12.733	1500	8	5.655	4½	7.171
5	5.563	5.047	.258	14.617	14.946	1500	8	6.322	5½	11.456
6	6.625	6.065	.280	18.974	19.338	1500	8	7.377	5½	13.446
7	7.625	7.023	.301	23.544	23.936	1200	8	8.371	5½	15.296
8	8.625	7.981	.322	28.554	29.167	1200	8	9.479	6½	23.465

The following notes apply to both tables:

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise specified.

Taper of threads is ¾ inch diameter per foot length for all sizes.

The weight per foot of tubing with threads and couplings is based on a length of 20 feet, including the couplings, but shipping lengths of small sizes will usually average less than 20 feet.

All weights given in pounds. All dimensions given in inches.

For illustration showing joints, see Figs. 7 and 8.

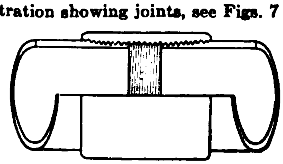


Fig. 7.—Section of Allison vanishing-thread tubing coupling and joint. Not upset.

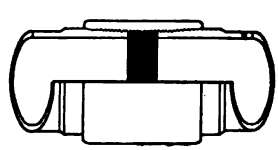


Fig. 8.—Section of Allison vanishing-thread tubing coupling and joint. Ends upset.

External Upset Tubing

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings			Diameter	Length	Weight
1¼	1.660	1.380	0.140	2.272	2.300	1800	11½	2.200	2¾	1.049
1½	1.900	1.610	.145	2.717	1.752	1800	11½	2.481	2¾	1.049
2	2.375	2.041	.167	3.938	4.000	2200	11½	3.060	3⅜	2.329
2	2.375	1.995	.190	4.433	4.500	2500	11½	3.060	3⅜	2.329
2½	2.875	2.441	.217	6.160	6.250	2200	11½	3.668	4⅛	3.891
3	3.500	3.018	.241	8.388	8.627	2000	10	4.504	5⅛	7.627
4	4.500	3.958	.271	12.240	12.500	1800	10	5.349	6⅛	9.511

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise specified.

Taper of threads is ¾ inch diameter per foot length for all sizes.

The weight per foot of tubing with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths will usually average less than 20 feet.

All weights given in pounds. All dimensions given in inches.

For illustration showing joint, see Fig. 9.

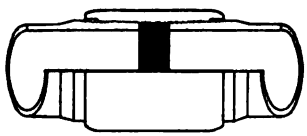


Fig. 9.—Section of external upset tubing coupling and joint.

Oil Well Tubing

All weights and dimenisons are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings			Diameter	Length	Weight
1¼	1.660	1.380	0.140	2.272	2.300	1800	11½	2.054	2¾	0.974
1½	1.900	1.610	.145	2.717	2.748	1800	11½	2.294	2¾	1.103
2	2.375	2.041	.167	3.938	4.000	2200	11½	2.841	3⅜	2.146
2	2.375	1.995	.190	4.433	4.500	2500	11½	2.841	3⅜	2.146
2½	2.875	2.469	.203	5.793	5.897	2000	11½	3.449	4⅛	3.636
2½	2.875	2.441	.217	6.160	6.250	2200	11½	3.449	4⅛	3.636
3	3.500	3.068	.216	7.575	7.694	1800	11½	4.074	4⅛	4.366
3	3.500	3.018	.241	8.388	8.500	2000	11½	4.074	4⅛	4.366
3	3.500	2.922	.289	9.910	10.000	2200	11½	4.074	4⅛	4.366
3½	4.000	3.548	.226	9.109	9.261	1500	8	4.628	4⅛	5.510
4	4.500	4.026	.237	10.790	10.980	1500	8	5.233	4⅛	6.673
4	4.500	3.990	.255	11.561	11.750	1800	8	5.233	4⅛	6.673

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise specified.

Taper of threads is ¾ inch diameter per foot length for all sizes.

The weight per foot of tubing with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.

All weights given in pounds. All dimensions given in inches.

Interior Upset Rotary Pipe

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings			Diameter	Length	Weight
2½	2.875	2.323	0.276	7.661	7.841	2000	8	3.564	6½	6.743
2½	2.875	2.143	.366	9.807	10.000	2500	8	3.678	6½	7.844
3	3.500	2.900	.300	10.252	10.486	2000	8	4.248	6½	8.777
4	4.500	3.958	.271	12.240	12.632	1800	8	5.256	7½	14.296
4	4.500	3.826	.337	14.983	15.323	2000	8	5.256	7½	14.296
4½	5.000	4.388	.306	15.340	15.737	1600	8	5.756	7½	15.787
5	5.563	4.975	.294	16.544	17.000	1600	8	6.303	8½	18.472
5	5.563	4.859	.352	19.590	20.000	1900	8	6.303	8½	18.472
6	6.625	6.065	.280	18.974	19.551	1500	8	7.350	8½	22.994
6	6.625	5.937	.344	23.076	23.566	1500	8	7.350	8½	22.994
6	6.625	5.761	.432	28.573	28.948	1800	8	7.350	8½	22.994

In addition to the test pressure applied the pipe is jarred with a hammer while under pressure.
The permissible variation in weight is 5 per cent above and 5 per cent below.
Furnished with threads and couplings and in random lengths unless otherwise specified.
Taper of threads is ¾ inch diameter per foot length for all sizes.
The weight per foot of pipe with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.
All weights given in pounds. All dimensions given in inches.

Diamond BX Drive Pipe

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings			Diameter	Length	Weight
4¼	4.750	4.082	0.334	15.752	16.000	1800	10	5.357	6½	10.112
4½	5.000	4.506	.247	12.538	12.850	1400	10	5.686	6½	10.734
4½	5.000	4.424	.288	14.493	15.000	1700	10	5.923	6½	14.299

The permissible variation in weight is 5 per cent above and 5 per cent below.
Furnished with threads and couplings and in random lengths unless otherwise specified.
Taper of threads is ¾ inch diameter per foot length for all sizes.
The weight per foot of pipe with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.
All weights given in pounds. All dimensions given in inches.
In addition to the test pressure applied the pipe is jarred with a hammer while under pressure.

Drive Pipe

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings			Diameter	Length	Weight
2	2.375	2.067	0.154	3.652	3.730	750	11½	2.923	3⅝	2.380
2½	2.875	2.469	.203	5.793	5.906	750	8	3.486	4⅛	3.748
3	3.500	3.068	.216	7.575	7.705	750	8	4.111	4⅛	4.493
3½	4.000	3.548	.226	9.109	9.294	750	8	4.723	4⅛	5.973
4	4.500	4.026	.237	10.790	10.995	750	8	5.223	4⅛	6.740
4½	5.000	4.506	.247	12.538	12.758	750	8	5.723	4⅛	7.439
5	5.563	5.047	.258	14.617	14.989	750	8	6.410	5⅛	11.781
6	6.625	6.065	.280	18.974	19.408	750	8	7.473	5⅛	13.956
7	7.625	7.023	.301	23.544	24.021	750	8	8.474	5⅛	15.955
8	8.625	8.071	.277	24.696	25.495	650	8	9.588	6⅛	24.343
8	8.625	7.981	.322	28.554	29.303	750	8	9.588	6⅛	24.343
8	8.625	7.917	.354	31.270	32.334	750	8	9.882	6⅛	31.320
9	9.625	8.941	.342	33.907	34.711	750	8	10.588	6⅛	27.035
10	10.750	10.192	.279	31.201	32.631	650	8	11.950	6⅛	40.108
10	10.750	10.136	.307	34.240	35.628	750	8	11.950	6⅝	40.108
10	10.750	10.020	.365	40.483	41.785	750	8	11.950	6⅝	40.108
11	11.750	11.000	.375	45.557	46.953	750	8	12.950	6⅝	43.664
12	12.750	12.090	.330	43.773	45.358	600	8	13.950	6⅝	47.220
12	12.750	12.000	.375	49.562	51.067	750	8	13.950	6⅝	47.220
14 O. D.	14.000	13.250	.375	54.568	56.849	750	8	15.438	7⅛	66.024
15 O. D.	15.000	14.250	.375	58.573	61.005	750	8	16.438	7⅛	70.533
16 O. D.	16.000	15.250	.375	62.579	65.161	500	8	17.438	7⅛	75.043
17 O. D.	17.000	16.214	.393	69.704	73.000	500	8	18.675	7⅛	91.746
18 O. D.	18.000	17.182	.409	76.840	81.000	500	8	19.913	7⅛	109.669
20 O. D.	20.000	19.182	.409	85.577	90.000	500	8	21.913	7⅛	121.298

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise specified.

Taper of threads is ¾ inch from 2 inches, to 5 inches and $\frac{1}{16}$ inch from 6 inches to 20 inches.

The weight per foot of pipe with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.

All weights given in pounds. All dimensions given in inches.

Rotary Drill Pipe—Lap-Welded

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings			Diameter	Length	Weight
*2½	2.875	2.323	0.276	7.661	7.830	2000	8	3.603	5⅛	5.888
*2½	2.875	2.143	.366	9.807	10.000	2500	8	3.693	5⅝	7.316
*3	3.500	2.764	.368	12.309	12.500	2000	8	4.248	6⅛	8.777
4	4.500	4.026	.237	10.790	11.157	1500	8	5.303	6⅛	11.768
4	4.500	3.990	.255	11.561	11.916	1500	8	5.303	6⅛	11.768
4	4.500	3.962	.269	12.155	12.500	1800	8	5.303	6⅛	11.768
*4	4.500	3.826	.337	14.983	15.000	2000	8	5.303	6⅛	11.768
4½	5.000	4.506	.247	12.538	12.933	1500	8	5.803	6⅛	12.988
4½	5.000	4.396	.302	15.152	15.500	1600	8	5.803	6⅛	12.988
*4½	5.000	4.290	.355	17.611	18.000	1800	8	5.803	6⅛	12.988
5	5.563	5.047	.258	14.617	15.094	1500	8	6.334	7⅛	16.562
5	5.563	4.955	.304	17.074	17.500	1600	8	6.334	7⅛	16.562
*5	5.563	4.813	.375	20.778	21.000	1800	8	6.334	7⅛	16.562
6	6.625	6.065	.280	18.974	19.507	1500	8	7.396	7⅛	19.561
6	6.625	5.939	.343	23.012	23.500	1500	8	7.396	7⅛	19.561
*6	6.625	5.761	.432	28.573	29.000	1800	8	7.396	7⅛	19.561

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise specified.

Taper of thread is ¾ inch diameter per foot length for all sizes.

The weight per foot of pipe with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.

All weights given in pounds. All dimensions given in inches.

* In these sizes the pipe is jarred with a hammer while under pressure.

Seamless Interior Upset Drill Pipe

All weights and dimensions are nominal

Size	Diameters		Thickness	Weight per Foot		Test pressure in pounds	Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings			Diameter	Length	Weight
2	2.375	2.000	0.1875	4.380	4.477	2500	10	2.892	5⅛	3.503
2½	2.875	2.469	.203	5.793	6.002	2200	8	3.564	6⅛	6.743
2½	2.875	2.323	.276	7.661	7.841	2500	8	3.564	6⅛	6.743
3	3.500	3.063	.2187	7.665	7.939	1800	8	4.248	6⅛	8.777
3½	4.000	3.500	.250	10.012	10.366	2000	8	4.771	7⅛	12.060
4	4.500	4.000	.250	11.347	11.756	1800	8	5.256	7⅜	14.296
4	4.500	3.958	.271	12.240	12.632	1900	8	5.256	7⅜	14.296
4	4.500	3.826	.337	14.983	15.323	2200	8	5.256	7⅜	14.296
4½	5.000	4.500	.250	12.682	13.130	1700	8	5.756	7⅝	15.787
5	5.563	4.975	.294	16.544	17.000	1700	8	6.303	8⅛	18.472
5	5.563	4.859	.352	19.590	20.000	2000	8	6.303	8⅛	18.472
6	6.625	6.065	.280	18.974	19.551	1600	8	7.350	8⅝	22.994
6	6.625	5.761	.432	28.573	28.948	2000	8	7.350	8⅝	22.994

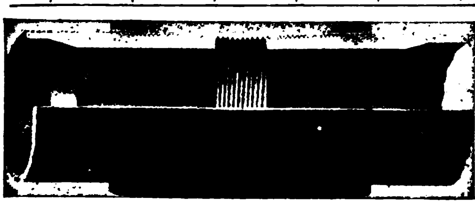


FIG. 10.—Seamless interior-upset drill pipe.

The permissible variation in weight is 5 per cent above and 5 per cent below.

All weights given in pounds. All dimensions given in inches.

Furnished in threads and couplings and n random lengths, 18 to 22 feet, unless otherwise specified.

Taper of threads is ¾ inch diameter per oot length for all sizes.

For illustration showing joint, see Fig. 10.

Collapsing Pressures of Steel Tubes

Next to the strength of joints in tubular material for drilling, operators are probably most concerned with collapsing pressures and the protection against them offered by the casing.

The strength of casing to resist external or collapsing pressures is often of vital importance when the well is bailed dry and the water column around the casing is of considerable height. Such pressure is represented by the difference in height of the fluid inside and outside the casing.

Professor Stewart's investigation.—The power of pipe to resist collapsing pressures has been the subject of a thorough investigation covering four years, by Professor R. T. Stewart. Concerning this investigation, Mr. F. B. Tough makes the following remarks in discussing the pressures allowable on commercial well casings:[2]

"The most authentic information at hand on this subject is that published by Stewart.[3] This paper formed the basis of a study by C. Naramore and R. S. Hazeltine, at Coalinga, Cal., in 1911. Later, Hazeltine presented a paper[4] on the results of Stewart's work as applied to the needs of the oil industry. All of these papers will repay a thorough study by anyone facing water problems in drilling wells.

"The following abstract from Stewart's paper is of especial interest:

"'1. The length of tube, between transverse joints tending to hold it to a circular form, has no practical influence upon the collapsing pressure of a commercial lap-welded steel tube so long as this length is not less than about 6 diameters of tube.

'2. The formulae, as based upon the present research, for the collapsing pressures of modern lap-welded Bessemer steel tubes, are as follows:

$$P=86{,}670\frac{t}{D}-1{,}386, \quad \ldots \ldots \ldots \ldots \quad (A)$$

$$P=50{,}210{,}000\left(\frac{t}{D}\right)^3, \quad \ldots \ldots \ldots \ldots \quad (B)$$

where P = collapsing pressure, pounds per square inch;
D = outside diameter of tube in inches;
t = thickness of wall in inches.

'Formula (A) is for values of P less than 581 pounds, or for values of less than 0.023, while formula (B) is for values greater than these.

'These formulae, while strictly correct for tubes that are 20 feet in length between transverse joints tending to hold them to a circular form, are, at the same time, substantially correct for all lengths greater than about 6 diameters. They have been tested for seven sizes, ranging from 3 to 10 inches outside diameter, in all obtainable commercial thicknesses of wall, and are known to be correct for this range.'

"By the foregoing formulae one may compute the probable collapsing pressure for any commercial size of casing.

"Methods have been given for determining the probable pressure that will be carried on the water string of a particular well, and also the method for computing the collapsing pressure of the casing; it remains to discuss the proper safety factors to use. Quoting again from Stewart's report:

[1] National Tube Company, Bull. 15, "National Pipe for Drilling Purposes."

[2] Tough, F. B.—Bul. 163, Dept. of the Interior, "Method of Shutting off Water in Oil and Gas Wells," 1918.

[3] Stewart, R. T.—Collapsing Pressures of Bessemer Steel Lap-welded Tubes, 3 to 10 Inches in Diameter; Trans. Am. Soc. Mech. Eng., May, 1906.

[4] Hazeltine, R. S.—Collapsing Pressure of Steel Tubes; West. Engineering, Vol. 1, July, 1912, pp. 295–297.

Tables of Collapsing Pressures

Collapsing Pressures—Pounds per Square Inch

(Based on Professor Stewart's Formulae (A) and (B))

Formulae

$P = 86{,}670t/D - 1386$, . . (A) $P = 50{,}210{,}000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches							
	1.000	1.050	1.125	1.250	1.315	1.375	1.500	1.660
0.01								
.02	402	347	282	206				
.03	1,214	1,090	925	694	596	521	402	
.04	2,081	1,916	1,696	1,387	1,250	1,135	925	
.05	2,948	2,741	2,466	2,081	1,909	1,766	1,503	
.06	3,814	3,567	3,236	2,774	2,568	2,396	2,081	1,747
.07	4,681	4,392	4,007	3,468	3,228	3,026	2,659	2,269
.08	5,548	5,217	4,777	4,161	3,887	3,657	3,236	2,791
.09	6,414	6,043	5,548	4,854	4,546	4,287	3,814	3,313
.10	7,281	6,868	6,318	5,548	5,205	4,917	4,392	3,835
.11	8,148	7,694	7,088	6,241	5,864	5,548	4,970	4,357
.12	9,014	8,519	7,859	6,934	6,523	6,178	5,548	4,879
.13	9,881	9,345	8,629	7,628	7,182	6,808	6,125	5,401
.14	10,748	10,170	9,400	8,321	7,841	7,439	6,703	5,923
.15	11,615	10,995	10,170	9,014	8,500	8,069	7,281	6,446
.16	12,481	11,821	10,940	9,708	9,159	8,699	7,859	6,968
.17	13,348	12,646	11,711	10,401	9,818	9,330	8,437	7,490
.18	14,215	13,472	12,481	11,094	10,478	9,960	9,014	8,012
.19	15,081	14,297	13,252	11,788	11,137	10,590	9,592	8,534
.20	15,948	15,123	14,022	12,481	11,796	11,221	10,170	9,056
.21	16,815	15,948	14,792	13,175	12,455	11,851	10,748	9,578
.22	17,681	16,773	15,563	13,868	13,114	12,481	11,326	10,100
.23	18,548	17,599	16,333	14,561	13,773	13,112	11,903	10,622
.24	19,415	18,424	17,104	15,255	14,432	13,742	12,481	11,145
.25	20,282	19,250	17,874	15,948	15,091	14,372	13,059	11,667
.26	21,148	20,075	18,644	16,641	15,750	15,003	13,637	12,189
.27	22,015	20,901	19,415	17,335	16,409	15,633	14,215	12,711
.28	22,882	21,726	20,185	18,028	17,068	16,263	14,792	13,233
.29	23,748	22,551	20,956	18,721	17,728	16,893	15,370	13,755
.30	24,615	23,377	21,726	19,415	18,387	17,524	15,948	14,277
.31	......	24,202	22,496	20,108	19,046	18,154	16,526	14,799
.32	......	......	......	20,802	19,705	18,784	17,104	15,321
.33	......	......	......	21,495	20,364	19,415	17,681	15,844
.34	......	......	......	22,188	21,023	20,045	18,259	16,366
.35	......	......	......	22,882	21,682	20,675	18,837	16,888
.36	......	......	......	23,575	22,341	21,306	19,415	17,410
.37	......	......	......	24,268	23,000	21,936	19,993	17,932
.38	......	......	......	......	......	......	......	18,454
.39	......	......	......	......	......	......	......	18,976
.40	......	......	......	......	......	......	......	......
.41	......	......	......	......	......	......	......	......
.42	......	......	......	......	......	......	......	......
.43	......	......	......	......	......	......	......	......
.44	......	......	......	......	......	......	......	......
.45	......	......	......	......	......	......	......	......
.46	......	......	......	......	......	......	......	......
.47	......	......	......	......	......	......	......	......
.48	......	......	......	......	......	......	......	......
.49	......	......	......	......	......	......	......	......

Collapsing Pressures—Pounds per Square Inch—(Continued)

(Based on Professor Stewart's Formulae (A) and (B)

Formulae

$P = 86,670t/D - 1386$, . . (A) $P = 50,210,000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches						
	1.750	1.875	1.900	2.000	2.250	2.375	2.500
0.01							
.02							
.03							
.04							
.05							
.06	1,586	1,387	1,351	1,214	925	804	694
.07	2,081	1,850	1,807	1,647	1,310	1,169	1,041
.08	2,576	2,312	2,263	2,081	1,696	1,533	1,387
.09	3,071	2,774	2,719	2,514	2,081	1,898	1,734
.10	3,567	3,236	3,176	2,948	2,466	2,263	2,081
.11	4,062	3,699	3,632	3,381	2,851	2,628	2,427
.12	4,557	4,161	4,088	3,814	3,236	2,993	2,774
.13	5,052	4,623	4,544	4,248	3,622	3,358	3,121
.14	5,548	5,085	5,000	4,681	4,007	3,723	3,468
.15	6,043	5,548	5,456	5,114	4,392	4,088	3,814
.16	6,538	6,010	5,913	5,548	4,777	4,453	4,161
.17	7,033	6,472	6,369	5,981	5,162	4,818	4,508
.18	7,529	6,934	6,825	6,414	5,548	5,183	4,854
.19	8,024	7,397	7,281	6,848	5,933	5,548	5,201
.20	8,519	7,859	7,737	7,281	6,318	5,913	5,548
.21	9,014	8,321	8,193	7,714	6,703	6,277	5,894
.22	9,510	8,783	8,649	8,148	7,088	6,642	6,241
.23	10,005	9,246	9,106	8,581	7,474	7,007	6,588
.24	10,500	9,708	9,562	9,014	7,859	7,372	6,934
.25	10,995	10,170	10,018	9,448	8,244	7,737	7,281
.26	11,491	10,632	10,474	9,881	8,629	8,102	7,628
.27	11,986	11,094	10,930	10,314	9,014	8,467	7,974
.28	12,481	11,557	11,386	10,748	9,400	8,832	8,321
.29	12,976	12,019	11,843	11,181	9,785	9,197	8,668
.30	13,472	12,481	12,299	11,615	10,170	9,562	9,014
.31	13,967	12,943	12,755	12,048	10,555	9,927	9,361
.32	14,462	13,406	13,211	12,481	10,940	10,292	9,708
.33	14,957	13,868	13,667	12,915	11,326	10,657	10,054
.34	15,453	14,330	14,123	13,348	11,711	11,021	10,401
.35	15,948	14,792	14,580	13,781	12,096	11,386	10,748
.36	16,443	15,255	15,036	14,215	12,481	11,751	11,094
.37	16,939	15,717	15,492	14,648	12,866	12,116	11,441
.38	17,434	16,179	15,948	15,081	13,252	12,481	11,788
.39	17,929	16,641	16,404	15,515	13,637	12,846	12,135
.40	18,424	17,104	16,860	15,948	14,022	13,211	12,481
.41	....	....	....	16,381	14,407	13,576	12,828
.42	....	....	....	16,815	14,792	13,941	13,175
.43	....	....	....	17,248	15,178	14,306	13,521
.44	....	....	....	17,681	15,563	14,671	13,868
.45	....	....	....	....	....	15,036	14,215
.46	....	....	....	....	....	15,401	14,561
.47	....	....	....	....	....	....	....
.48	....	....	....	....	....	....	....
.49	....	....	....	....	....	....	....

Collapsing Pressures—Pounds per Square Inch—(Continued)

(Based on Professor Stewart's Formulae (A) and (B))

Formulae

$P = 86{,}670t/D - 1386$, . . (A) $\qquad P = 50{,}210{,}000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches						
	2.750	2.875	3.000	3.250	3.500	3.750	4.000
0.01							
.02							
.03							
.04							
.05							
.06	521						
.07	820						
.08	1,135						
.09	1,450	1,327	1,214	1,014	843		
.10	1,766	1,629	1,503	1,281	1,090		
.11	2,081	1,930	1,792	1,547	1,338		
.12	2,396	2,232	2,081	1,814	1,586	1387	1214
.13	2,711	2,533	2,370	2,081	1,833	1619	1431
.14	3,026	2,834	2,659	2,347	2,081	1850	1647
.15	3,341	3,136	2,948	2,614	2,328	2081	1864
.16	3,657	3,437	3,236	2,881	2,576	2312	2081
.17	3,972	3,739	3,525	3,148	2,824	2543	2297
.18	4,287	4,040	3,814	3,414	3,071	2774	2514
.19	4,602	4,342	4,103	3,681	3,319	3005	2731
.20	4,917	4,643	4,392	3,947	3,567	3236	2948
.21	5,232	4,945	4,681	4,214	3,814	3468	3164
.22	5,548	5,246	4,970	4,481	4,062	3699	3381
.23	5,863	5,548	5,259	4,748	4,309	3930	3598
.24	6,178	5,849	5,548	5,014	4,557	4161	3814
.25	6,493	6,151	5,836	5,281	4,805	4392	4031
.26	6,808	6,452	6,125	5,548	5,052	4623	4248
.27	7,123	6,753	6,414	5,814	5,300	4854	4464
.28	7,439	7,055	6,703	6,081	5,548	5085	4681
.29	7,754	7,356	6,992	6,348	5,795	5316	4898
.30	8,069	7,658	7,281	6,614	6,043	5548	5114
.31	8,384	7,959	7,570	6,881	6,290	5779	5331
.32	8,699	8,261	7,859	7,148	6,538	6010	5548
.33	9,014	8,562	8,148	7,414	6,786	6241	5764
.34	9,330	8,864	8,437	7,681	7,033	6472	5981
.35	9,645	9,165	8,726	7,948	7,281	6703	6198
.36	9,960	9,467	9,014	8,214	7,529	6934	6414
.37	10,275	9,768	9,303	8,481	7,776	7165	6631
.38	10,590	10,070	9,592	8,748	8,024	7397	6848
.39	10,905	10,371	9,881	9,014	8,272	7628	7064
.40	11,221	10,672	10,170	9,281	8,519	7759	7281
.41	11,536	10,974	10,459	9,548	8,767	8090	7498
.42	11,851	11,275	10,748	9,814	9,014	8321	7714
.43	12,166	11,577	11,037	10,081	9,262	8552	7931
.44	12,481	11,878	11,326	10,348	9,510	8783	8148
.45	12,796	12,180	11,615	10,615	9,757	9014	8364
.46	13,112	12,481	11,903	10,881	10,005	9246	8581
.47	....	12,783	12,192	11,148	10,253	9477	8798
.48	....	13,084	12,481	11,414	10,500	9708	9014
.49	....	13,386	12,770	11,681	10,748	9939	9231

Collapsing Pressures—Pounds per Square Inch—(Continued)
(Based on Professor Stewart's Formulae (A) and (B))
Formulae

$P = 86{,}670t/D - 1386$, . . (A) $P = 50{,}210{,}000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches						
	2.750	2.875	3.000	3.250	3.500	3.750	4.000
0.50	....	13,687	13,059	11,948	10,995	10,170	9,448
.51	....	13,988	13,348	12,215	11,243	10,401	9,664
.52	....	14,290	13,637	12,481	11,491	10,632	9,881
.53	....	14,591	13,926	12,748	11,738	10,863	10,098
.54	....	14,893	14,215	13,015	11,986	11,094	10,314
.55	....	15,194	14,503	13,281	12,234	11,326	10,531
.56	....	15,496	14,792	13,548	12,481	11,557	10,748
.57	....	....	....	....	12,729	11,788	10,964
.58	....	....	....	....	12,976	12,019	11,181
.59	....	....	....	....	13,224	12,250	11,398
.60	....	....	....	....	13,472	12,481	11,615
.61	....	....	....	....	....	12,712	11,831
.62	....	....	....	....	....	12,943	12,048
.63	....	....	....	....	....	13,175	12,265
.64	....	....	....	....	....	13,406	12,481
.65	....	....	....	....	....	....	....
.66	....	....	....	....	....	....	....
.67	....	....	....	....	....	....	....
.68	....	....	....	....	....	....	....
.69	....	....	....	....	....	....	....
.70	....	....	....	....	....	....	....
.71	....	....	....	....	....	....	....
.72	....	....	....	....	....	....	....
.73	....	....	....	....	....	....	....
.74	....	....	....	....	....	....	....
.75	....	....	....	....	....	....	....
.76	....	....	....	....	....	....	....
.77	....	....	....	....	....	....	....
.78	....	....	....	....	....	....	....
.79	....	....	....	....	....	....	....
.80	....	....	....	....	....	....	....
.81	....	....	....	....	....	....	....
.82	....	....	....	....	....	....	....
.83	....	....	....	....	....	....	....
.84	....	....	....	....	....	....	....
.85	....	....	....	....	....	....	....
.86	....	....	....	....	....	....	....
.87	....	....	....	....	....	....	....
.88	....	....	....	....	....	....	....
.89	....	....	....	....	....	....	....
.90	....	....	....	....	....	....	....
.91	....	....	....	....	....	....	....
.92	....	....	....	....	....	....	....
.93	....	....	....	....	....	....	....
.94	....	....	....	....	....	....	....
.95	....	....	....	....	....	....	....
.96	....	....	....	....	....	....	....
97	....	....	....	....	....	....	....
.98	....	....	....	....	....	....	....
.99	....	....	....	....	....	....	....
1.00	....	....	....	....	....	....	....

Collapsing Pressures—Pounds per Square Inch—(Continued)

(Based on Professor Stewart's Formulae (A) and (B))

Formulae

$P = 86{,}670t/D - 1386$, . . (A) $P = 50{,}210{,}000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches						
	4.250	4.500	4.750	5.000	5.250	5.500	5.563
0.01							
.02							
.03							
.04							
.05							
.06							
.07							
.08							
.09							
.10							
.11							
.12	1061	925					
.13	1265	1118	986	867	760	663	
.14	1469	1310	1169	1041	925	820	795
.15	1673	1503	1351	1214	1090	978	951
.16	1877	1696	1533	1387	1255	1135	1107
.17	2081	1888	1716	1561	1420	1293	1263
.18	2285	2081	1898	1734	1586	1450	1418
.19	2489	2273	2081	1907	1751	1608	1574
.20	2693	2466	2263	2081	1916	1766	1730
.21	2897	2659	2446	2254	2081	1923	1886
.22	3100	2851	2628	2427	2246	2081	2042
.23	3304	3044	2811	2601	2411	2238	2197
.24	3508	3236	2993	2774	2576	2396	2353
.25	3712	3429	3176	2948	2741	2554	2509
.26	3916	3622	3358	3121	2906	2711	2665
.27	4120	3814	3540	3294	3071	2869	2821
.28	4324	4007	3723	3468	3236	3026	2976
.29	4528	4199	3905	3641	3401	3184	3132
.30	4732	4392	4088	3814	3567	3341	3288
.31	4936	4585	4270	3988	3732	3499	3444
.32	5140	4777	4453	4161	3897	3657	3600
.33	5344	4970	4635	4334	4062	3814	3755
.34	5548	5162	4818	4508	4227	3972	3911
.35	5752	5355	5000	4681	4392	4129	4067
.36	5955	5548	5183	4854	4557	4287	4223
.37	6159	5740	5365	5028	4722	4445	4378
.38	6363	5933	5548	5201	4887	4602	4534
.39	6567	6125	5730	5374	5052	4760	4690
.40	6771	6318	5913	5548	5217	4917	4846
.41	6975	6511	6095	5721	5383	5075	5002
.42	7179	6703	6277	5894	5548	5232	5157
.43	7383	6896	6460	6068	5713	5390	5313
.44	7587	7088	6642	6241	5878	5548	5469
.45	7791	7281	6825	6414	6043	5705	5625
.46	7995	7474	7007	6588	6208	5863	5781
.47	8199	7666	7190	6761	6373	6020	5936
.48	8403	7859	7372	6934	6538	6178	6092
.49	8607	8051	7555	7108	6703	6336	6248

Collapsing Pressures—Pounds per Square Inch—(Continued)

(Based on Professor Stewart's Formulae (A) and (B))

Formulae

$P = 86{,}670t/D - 1386$, . . (A) $P = 50{,}210{,}000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches						
	4.250	4.500	4.750	5.000	5.250	5.500	5.563
0.50	8,810	8,244	7,737	7,281	6,868	6493	6,404
.51	9,014	8,437	7,920	7,454	7,033	6651	6,560
.52	9,218	8,629	8,102	7,628	7,198	6808	6,715
.53	9,422	8,822	8,285	7,801	7,364	6966	6,871
.54	9,626	9,014	8,467	7,974	7,529	7123	7,027
.55	9,830	9,207	8,649	8,148	7,694	7281	7,183
.56	10,034	9,400	8,832	8,321	7,859	7439	7,339
.57	10,238	9,592	9,014	8,494	8,024	7596	7,494
.58	10,442	9,785	9,197	8,668	8,189	7754	7,650
.59	10,646	9,977	9,379	8,841	8,354	7911	7,806
.60	10,850	10,170	9,562	9,014	8,519	8069	7,962
.61	11,054	10,363	9,744	9,188	8,684	8226	8,118
.62	11,258	10,555	9,927	9,361	8,849	8384	8,273
.63	11,462	10,748	10,109	9,534	9,014	8542	8,429
.64	11,665	10,940	10,292	9,708	9,179	8699	8,585
.65	....	11,133	10,474	9,881	9,345	8857	8,741
.66	....	11,326	10,657	10,054	9,510	9014	8,897
.67	....	11,518	10,839	10,228	9,675	9172	9,052
.68	....	11,711	11,022	10,401	9,840	9330	9,208
.69	....	....	....	10,574	10,005	9487	9,364
.70	....	....	....	10,748	10,170	9645	9,520
.71	....	....	....	10,921	10,335	9802	9,676
.72	....	....	....	....	....	....	9,831
.73	....	....	....	....	....	....	9,987
.74	....	....	....	....	....	....	10,143
.75	....	....	....	....	....	....	10,299
.76	....	....	....	....	....	....	....
.77	....	....	....	....	....	....	....
.78	....	....	....	....	....	....	....
.79	....	....	....	....	....	....	....
.80	....	....	....	....	....	....	....
.81	....	....	....	....	....	....	....
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.97	....	....	....	....	....	....	....
.98	....	....	....	....	....	....	....
.99	....	....	....	....	....	....	....
1.00	....	....	....	....	....	....	....

Collapsing Pressures—Pounds per Square Inch—(Continued)

(Based on Professor Stewart's Formulae (A) and (B))

Formulae

$P = 86{,}670t/D - 1386$, . . (A) $P = 50{,}210{,}000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches						
	6.000	6.500	6.625	7.000	7.500	7.625	8.000
0.01							
.02							
.03							
.04							
.05							
.06							
.07							
.08							
.09							
.10							
.11							
.12							
.13							
.14	636	502					
.15	781	614	583	494	402	382	331
.16	925	747	707	600	488	464	402
.17	1070	881	838	719	585	556	482
.18	1214	1014	969	843	694	660	572
.19	1359	1147	1100	966	810	774	672
.20	1503	1281	1230	1090	925	887	781
.21	1647	1414	1361	1214	1041	1001	889
.22	1792	1547	1492	1338	1156	1115	997
.23	1936	1681	1623	1462	1272	1228	1106
.24	2081	1814	1754	1586	1387	1342	1214
.25	2225	1947	1885	1709	1503	1456	1322
.26	2370	2081	2015	1833	1619	1569	1431
.27	2514	2214	2146	1957	1734	1683	1539
.28	2659	2347	2277	2081	1850	1797	1647
.29	2803	2481	2408	2205	1965	1910	1756
.30	2948	2614	2539	2328	2081	2024	1864
.31	3092	2747	2670	2452	2196	2138	1972
.32	3236	2881	2800	2576	2312	2251	2081
.33	3381	3014	2931	2700	2427	2365	2189
.34	3525	3148	3062	2824	2543	2479	2297
.35	3670	3281	3193	2948	2659	2592	2406
.36	3814	3414	3324	3071	2774	2706	2514
.37	3959	3548	3454	3195	2890	2820	2622
.38	4103	3681	3585	3319	3005	2933	2731
.39	4248	3814	3716	3443	3121	3047	2839
.40	4392	3948	3847	3567	3236	3161	2948
.41	4536	4081	3978	3690	3352	3274	3056
.42	4681	4214	4109	3814	3468	3388	3164
.43	4825	4348	4239	3938	3583	3502	3273
.44	4970	4481	4370	4062	3699	3615	3381
.45	5114	4614	4501	4186	3814	3729	3489
.46	5259	4748	4632	4309	3930	3843	3598
.47	5403	4881	4763	4433	4045	3956	4706
.48	5548	5014	4894	4557	4161	4070	4814
.49	5692	5148	5024	4681	4276	4184	3923

Collapsing Pressures—Pounds per Square Inch—(Continued)

(Based on Professor Stewart's Formulae (A) and (B))

Formulae

$P = 86{,}670t/D - 1386$, . . (A) $P = 50{,}210{,}000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches						
	6.000	6.500	6.625	7.000	7.500	7.625	8.000
0.50	5837	5281	5155	4805	4392	4297	4031
.51	5981	5414	5286	4929	4508	4411	4139
.52	6125	5548	5417	5052	4623	4525	4248
.53	6270	5681	5548	5176	4739	4638	4356
.54	6414	5814	5678	5300	4854	4752	4464
.55	6559	5948	5809	5424	4970	4866	4573
.56	6703	6081	5940	5548	5085	4979	4681
.57	6848	6214	6071	5671	5201	4093	4789
.58	6992	6348	6202	5795	5316	5207	4898
.59	7137	6481	6333	5919	5432	5320	5006
.60	7281	6614	6463	6043	5548	5434	5114
.61	7425	6748	6594	6167	5663	5548	5223
.62	7570	6881	6725	6290	5779	5661	5331
.63	7714	7014	6856	6414	5894	5775	5439
.64	7859	7148	6987	6538	6010	5889	5548
.65	8003	7281	7117	6662	6125	6002	5656
.66	8148	7414	7248	6786	6241	6116	5764
.67	8292	7548	7379	6910	6357	6230	5873
.68	8437	7681	7510	7033	6472	6343	5981
.69	8581	7814	7641	7157	6588	6457	6089
.70	8726	7948	7772	7281	6703	6571	6198
.71	8870	8081	7902	7405	6819	6684	6306
.72	9014	8214	8033	7529	6934	6798	6414
.73	9159	8348	8164	7652	7050	6912	6523
.74	9303	8481	8295	7776	7165	7025	6631
.75	9448	8614	8426	7900	7281	7139	6739
.76	....	....	8557	8024	7397	7253	6848
.77	....	....	8687	8148	7512	7366	6956
.78	....	....	8818	8272	7628	7480	7064
.79	....	....	8949	8395	7743	7594	7173
.80	....	....	9080	8519	7859	7707	7281
.81	....	....	9211	8643	7974	7821	7389
.82	....	....	9341	8767	8090	7935	7498
.83	....	....	9472	8891	8205	8048	7606
.84	....	....	9603	9014	8321	8162	7714
.85	....	....	9734	9138	8437	8276	7823
.86	....	....	9865	9262	8552	8389	7931
.87	....	....	9996	9386	8668	8503	8039
.88	....	....	....	....	....	8617	8148
.89	....	....	....	....	....	....	....
.90	....	....	....	....	....	....	....
.91	....	....	....	....	....	....	....
.92	....	....	....	....	....	....	....
.93	....	....	....	....	....	....	....
.94	....	....	....	....	....	....	....
.95	....	....	....	....	....	....	....
.96	....	....	....	....	....	....	....
.97	....	....	....	....	....	....	....
.98	....	....	....	....	....	....	....
.99	....	....	....	....	....	....	....
1.00	....	....	....	....	....	....	....

Collapsing Pressures—Pounds per Square Inch—(Continued)

(Based on Professor Stewart's Formulae (A) and (B))

Formulae

$P = 86{,}670t/D - 1386$, . . (A) $P = 50{,}210{,}000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches						
	8.500	8.625	9.000	9.500	9.625	10.000	10.500
0.01							
.02							
.03							
.04							
.05							
.06							
.07							
.08							
.09							
.10							
.11							
.12							
.13							
.14							
.15	276						
.16	335	320	282	240	230		
.17	402	385	338	288	277	247	213
.18	477	456	402	341	328	293	253
.19	561	537	472	402	386	344	297
.20	653	624	551	468	450	402	347
.21	755	724	636	542	521	465	402
.22	857	825	733	621	600	535	462
.23	959	925	829	712	685	611	528
.24	1061	1026	925	804	775	694	600
.25	1163	1126	1022	895	865	781	678
.26	1265	1227	1118	986	955	867	760
.27	1367	1327	1214	1077	1045	954	843
.28	1469	1428	1310	1168	1135	1041	925
.29	1571	1528	1407	1260	1225	1127	1008
.30	1673	1629	1503	1351	1315	1214	1090
.31	1775	1729	1599	1442	1405	1301	1173
.32	1877	1830	1696	1533	1495	1387	1255
.33	1979	1930	1792	1625	1586	1474	1338
.34	2081	2031	1888	1716	1676	1561	1420
.35	2183	2131	1985	1807	1766	1647	1503
.36	2285	2232	2081	1898	1856	1734	1586
.37	2387	2332	2177	1990	1946	1821	1668
.38	2489	2433	2273	2081	2036	1907	1751
.39	2591	2533	2370	2172	2126	1994	1833
.40	2693	2633	2466	2263	2216	2081	1916
.41	2795	2734	2562	2355	2306	2167	1998
.42	2897	2834	2659	2446	2396	2254	2081
.43	2998	2935	2755	2537	2486	2341	2163
.44	3100	3035	2851	2628	2576	2427	2246
.45	3202	3136	2948	2719	2666	2514	2328
.46	3304	3236	3044	2811	2756	2601	2411
.47	3406	3337	3140	2902	2846	2687	2494
.48	3508	3437	3236	2993	2936	2774	2576
.49	3610	3538	3333	3084	3026	2861	2659

Collapsing Pressures—Pounds per Square Inch—(Continued)
(Based on Professor Stewart's Formulae (A) and (B))

Formulae

$P = 86{,}670t/D - 1386$, . . (A) $P = 50{,}210{,}000(t/D)^3$ . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of walls in inches.

Thickness	Outside diameter—inches						
	8.500	8.625	9.000	9.500	9.625	10.000	10.500
0.50	3712	3638	3429	3176	3116	2948	2741
.51	3814	3739	3525	3267	3206	3034	2824
.52	3916	3839	3622	3358	3296	3121	2906
.53	4018	3940	3718	3449	3386	3208	2989
.54	4120	4040	3814	3541	3477	3294	3071
.55	4222	4141	3910	3632	3567	3381	3154
.56	4324	4241	4007	3723	3657	3468	3236
.57	4426	4342	4103	3814	3747	3554	3319
.58	4528	4442	4199	3905	3837	3641	3401
.59	4630	4543	4296	3997	3927	3728	3484
.60	4732	4643	4392	4088	4017	3814	3567
.61	4834	4744	4488	4179	4107	3901	3649
.62	4936	4844	4585	4270	4197	3988	3732
.63	5038	4945	4681	4362	4287	4074	3814
.64	5140	5045	4777	4453	4377	4161	3897
.65	5242	5146	4873	4544	4467	4248	3979
.66	5344	5246	4970	4635	4557	4334	4062
.67	5446	5347	5066	4727	4647	4421	4144
.68	5548	5447	5162	4818	4737	4508	4227
.69	5650	5548	5259	4909	4827	4594	4309
.70	5752	5648	5355	5000	4917	4681	4392
.71	5853	5749	5451	5091	5007	4768	4475
.72	5955	5849	5548	5183	5097	4854	4557
.73	6057	5950	5644	5274	5187	4941	4640
.74	6159	6050	5740	5365	5277	5028	4722
.75	6261	6151	5836	5456	5368	5114	4805
.76	6363	6251	5933	5548	5458	5201	4887
.77	6465	6351	6029	5639	5548	5288	4970
.78	6567	6452	6125	5730	5638	5374	5052
.79	6669	6552	6222	5821	5728	5461	5135
.80	6771	6653	6318	5913	5818	5548	5217
.81	6873	6753	6414	6004	5908	5634	5300
.82	6975	6854	6511	6095	5998	5721	5383
.83	7077	6954	6607	6186	6088	5808	5465
.84	7179	7055	6703	6277	6178	5894	5548
.85	7281	7155	6799	6369	6268	5981	5630
.86	7383	7256	6896	6460	6358	6068	5713
.87	7485	7356	6992	6551	6448	6154	5795
.88	7587	7457	7088	6642	6538	6241	5878
.89	....	....	....	6734	6628	6328	5960
.90	....	....	....	6825	6718	6414	6043
.91	....	....	....	6916	6808	6501	6125
.92	....	....	....	7007	6898	6588	6208
.93	....	....	....	7099	6988	6674	6290
.94	....	....	....	7190	7078	6761	6373
.95	....	....	....	7281	7168	6848	6456
.96	....	....	....	7372	7258	6934	6538
.97	....	....	....	7464	7349	7021	6621
.98	....	....	....	7555	7439	7108	6703
.99	....	....	....	7646	7529	7194	6786
1.00	....	....	....	7737	7619	7281	6868

Collapsing Pressures—Pounds per Square Inch—(Continued)

(Based on Professor Stewart's Formulae (A) and (B))

Formulae

$P = 86{,}670t/D - 1386$, . . (A) $P = 50{,}210{,}000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches						
	10.750	11.000	11.500	11.750	12.000	12.500	12.750
0.01							
.02							
.03							
.04							
.05							
.06							
.07							
.08							
.09							
.10							
.11							
.12							
.13							
.14							
.15							
.16							
.17							
.18	236	220	192	180	170	150	141
.19	277	259	226	212	199	176	166
.20	323	302	264	248	232	206	194
.21	374	349	306	287	269	238	224
.22	430	402	351	329	309	274	258
.23	492	459	402	377	353	313	295
.24	559	522	456	428	402	355	335
.25	630	589	516	484	454	402	379
.26	710	663	580	544	511	452	426
.27	791	741	649	609	572	506	477
.28	871	820	724	679	636	564	532
.29	952	899	800	753	709	625	591
.30	1033	978	875	827	781	694	653
.31	1113	1057	950	901	853	763	721
.32	1194	1135	1026	974	925	833	789
.33	1275	1214	1101	1048	997	902	857
.34	1355	1293	1176	1122	1070	971	925
.35	1436	1372	1252	1196	1142	1041	993
.36	1516	1450	1327	1269	1214	1110	1061
.37	1597	1529	1403	1343	1286	1179	1129
.38	1678	1608	1478	1417	1359	1249	1197
.39	1758	1687	1553	1491	1431	1318	1265
.40	1839	1766	1629	1564	1503	1387	1333
.41	1920	1844	1704	1638	1575	1457	1401
.42	2000	1923	1779	1712	1647	1526	1469
.43	2081	2002	1855	1786	1720	1595	1537
.44	2161	2081	1930	1860	1792	1665	1605
.45	2242	2160	2205	1933	1864	1734	1673
.46	2323	2238	2081	2007	1936	1803	1741
.47	2403	2317	2156	2081	2009	1873	1809
.48	2484	2396	2232	2155	2081	1942	1877
.49	2565	2475	2307	2228	2153	2011	1945

Collapsing Pressures—Pounds per Square Inch

(Based on Professor Stewart's Formulae (A) and (B))

Formulae

$P=86{,}670t/D-1386$, . . (A) $P=50{,}210{,}000(t/D)^3$, . . (B)

where P = collapsing pressure in pounds per square inch;
D = outside diameter of tube in inches; t = thickness of wall in inches.

Thickness	Outside diameter—inches						
	10.750	11.000	11.500	11.750	12.000	12.500	12.750
0.50	2645	2554	2382	2302	2225	2081	2013
.51	2726	2632	2458	2376	2297	2150	2081
.52	2806	2711	2533	2450	2370	2219	2149
.53	2887	2790	2608	2523	2442	2289	2217
.54	2968	2869	2684	2597	2514	2358	2285
.55	3048	2947	2759	2671	2586	2427	2353
.56	3129	3026	2834	2745	2659	2497	2421
.57	3210	3105	2910	2818	2731	2566	2489
.58	3290	3184	2985	2892	2803	2635	2557
.59	3371	3263	3061	2966	2875	2705	2625
.60	3451	3341	3136	3040	2948	2774	2693
.61	3532	3420	3211	3113	3020	2843	2761
.62	3613	3499	3287	3187	3092	2913	2829
.63	3693	3578	3362	3261	3164	2982	2897
.64	3774	3657	3437	3335	3236	3052	2964
.65	3855	3735	3513	3409	3309	3121	3032
.66	3935	3814	3588	3482	3381	3190	3100
.67	4016	3893	3663	3556	3453	3260	3168
.68	4096	3972	3739	3630	3525	3329	3236
.69	4177	4051	3814	3704	3598	3398	3304
.70	4258	4129	3890	3777	3670	3468	3372
.71	4338	4208	3965	3851	3742	3537	3440
.72	4419	4287	4040	3925	3814	3606	3508
.73	4499	4366	4116	3999	3886	3676	3576
.74	4580	4445	4191	4072	3959	3745	3644
.75	4661	4523	4266	4146	4031	3814	3712
.76	4741	4602	4342	4220	4103	3884	3780
.77	4822	4681	4417	4294	4175	3953	3848
.78	4903	4760	4492	4367	4248	4022	3916
.79	4983	4838	4568	4441	4320	4092	3984
.80	5064	4917	4643	4515	4392	4161	4052
.81	5144	4996	4719	4589	4464	4230	4120
.82	5225	5075	4794	4662	4536	4300	4188
.83	5306	5154	4869	4736	4609	4369	4256
.84	5386	5232	4945	4810	4681	4438	4324
.85	5467	5311	5020	4884	4753	4508	4392
.86	5548	5390	5095	4958	4825	4577	4460
.87	5628	5469	5171	5031	4898	4646	4528
.88	5709	5548	5246	5105	4970	4716	4596
.89	5789	5626	5322	5179	5042	4785	4664
.90	5870	5705	5397	5253	5114	4854	4732
.91	5951	5784	5472	5326	5186	4924	4800
.92	6031	5863	5548	5400	5259	4993	4868
.93	6112	5942	5623	5474	5331	5062	4936
.94	6193	6020	5698	5548	5403	5132	5004
.95	6273	6099	5774	5621	5475	5201	5072
.96	6354	6178	5849	5695	5548	5270	5140
.97	6434	6257	5924	5769	5620	5340	5208
.98	6515	6336	6000	5843	5692	5409	5276
.99	6596	6414	6075	5916	5764	5478	5344
1.00	6676	6493	6151	5990	5836	5548	5412

"'Not one of the several hundred tubes tested failed at a pressure lower than 42 per cent less than the probable collapsing pressure, while 0.5 per cent of the number of tubes failed at 37 per cent and 2 per cent at 25 per cent less than that pressure. In other words, with an actual factor of safety of 1.75, . . . not one of the tubes tested would have failed.

'It would appear that:

'1. For the most favorable practical conditions, namely, when the tube is subjected only to stress due to fluid pressure and only the most trivial loss could result from its failure, a factor of safety of 3 would appear sufficient.

'2. When only a moderate amount of loss could result from failure, use a factor of 4.

'3. When considerable damage to property and loss of life might result from a failure of the tube, then use a factor of safety of at least 6.

'4. When the conditions of service are such as to cause the tube to become less capable of resisting collapsing pressure, such as the thinning of wall due to corrosion, the weakening of the material due to overheating, the creating of internal stress in the wall of the tube due to unequal heating, vibration, etc., the above factors of safety should be increased in proportion to the severity of these actions.'

"These recommendations by Stewart are absolutely sound engineering, and if a safety factor of 3 were used in oil-well work some costly redrilling jobs might be avoided. At the same time such a procedure would not only increase the cost of material, but would frequently necessitate decreasing the size of the next string of pipe to be inserted in the well, a serious disadvantage. The drilling proverb, 'Keep the hole as big as you can as long as you can,' is not to be lightly ignored.

"One fortunate circumstance is that while a string of casing is being subjected to severe drilling stresses such as pulling, driving, and jarring, the external and internal fluid pressures on the pipe are equalized. Not until the string is landed and the fluid lowered within it is any collapsing tendency developed; thus drilling and collapsing stresses are not coexistent."

The grinding action of boulders wedged against the side of the casing creates another condition that makes the power of resistance in the material to collapsing pressures most important. When this strain is such as to distort the shape but slightly, it is possible with uniformly good pipe to correct the damage without pulling the string. Usually a swedge on the drilling tools, worked up and down against the depression, will readily return the damaged portion to its original shape and permit the resumption of operations with minimum delay.

Strength of Tubes, Pipes, and Cylinders under Internal Fluid Pressure

In order to arrive at some definite conclusion as to what formula or formulae should be used for calculating the strength of tubes, pipes, and cylinders subjected to internal fluid pressure, the different published formulae have been investigated and compared. These are five in number; namely, the common formula, and those by Barlow, Lamé, Clavarino, and Birnie.

These formulae have been put into the simplest form for application to tubes, pipes and cylinders, and are reduced to a common notation for the sake of making an easy comparison. The notation used is as follows:

D_1 = outside diameter in inches;
D_2 = inside diameter in inches;
t = thickness of wall in inches;
p = internal gage pressure, or difference between internal and external fluid pressures, in pounds per square inch;
f = fiber stress in the wall in pounds per square inch.

The formulae here given are for the usual conditions of practice, namely, where the external pressure is atmospheric and the internal pressure is expressed as gage pressure. They are also applicable to cases where the external pressure is not excessive by taking p as the difference between the internal and external pressures.

In all that follows it is assumed that the length of the tube or pipe relative to its diameter is sufficiently great to eliminate the influence of end support tending to prevent rupture.

Nature of stress in a tube wall.—An internal fluid pressure may give rise (1) to a circumferential stress within the wall of a tube or pipe, or (2) to both a circumferential and a longitudinal stress acting jointly. In either case the tube wall is under radial compressive stress, as indicated by the arrows, Fig. 11 and 12.

Fig. 11 illustrates a tube with frictionless plungers fitted into its ends, the plungers being kept in place by the external forces, P, P, which exactly balance the internal fluid pressure tending to force them outward. In this case the tube wall is subjected only to the internal forces shown as acting at right angles to its inner surface. It is obvious that these forces can give rise to radial and circumferential stresses only in the tube wall. The value of the circumferential stress, f_t, in pounds per square inch, is

$$f_t = p\frac{D_2}{D_1 - D_2} = \frac{pD_2}{2t}. \qquad (1)$$

Fig. 12 illustrates the ordinary case of a tube or pipe with both ends closed. In this case the tube wall, as in Fig. 11, is subjected to the circumferential stress, f_t, along with the radial stress, and at the same time is subjected to the longitudinal stress

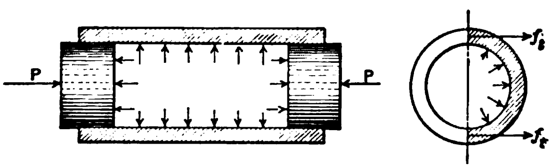

FIG. 11.

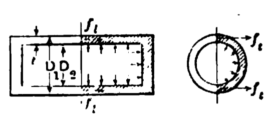

FIG. 12.

f_l. The longitudinal stress is caused by the internal fluid pressure tending to force the attached heads outward and expressed in pounds per square inch is

$$f_l = p\frac{D_2^2}{4(D^2+t)t}. \qquad (2)$$

When the thickness of wall, t, is relatively small with respect to the diameter, the longitudinal stress becomes approximately

$$f_l = \frac{pD_2}{4t}, \qquad (3)$$

or one-half the corresponding circumferential stress.

Common formula.—This is the formula generally found in books on mechanics. It is based on the condition that the tube wall is subjected to circumferential stress only (Fig. 11), and assumes (1) that the material of the tube wall is devoid of elasticity, and (2) that the stress is the same on all the circumferential fibers from the innermost to the outermost. These assumptions are only approximately true for tubes of comparatively thin walls, and are greatly in error for tubes having very thick walls.

Using the notation as given above, the formula is

$$\frac{p}{f} = 2\frac{t}{D_2}; \quad p = 2f\frac{t}{D_2}; \quad t = \tfrac{1}{2}D_2\frac{p}{f}; \quad f = \tfrac{1}{2}D_2\frac{p}{t}. \qquad (4)$$

Referring to the curves, Figs. 13 and 14, it will be seen that the common formula gives quite close results for comparatively thin walls when used for the condi ions shown in Fig. 11, for which Birnie's formula is theoretically correct. The error increases as the thickness of wall becomes relatively greater, reaching 10 per cent for a thickness ratio, $\frac{t}{D_1}$, of about 0.05. For thick walls the error is great; for example, when $\frac{t}{D_1}$ equals 0.25 the value of $\frac{p}{f}$ is about 100 per cent in error. It should be observed when applying the common formula to this case that the error is always on the side of danger.

For the conditions shown in Fig. 12, that is, when the tube is subjected to the stresses due to an internal fluid pressure acting jointly on the tube wall and its closed ends, for which Clavarino's formula is theoretically correct, the curves show for a thickness ratio, $\frac{t}{D_1}$, less than 0.07, that the common formula errs on the side of safety, the greatest error being about 12 per cent; while for thickness ratios greater than 0.07 the error is on the side of danger, reaching 10 per cent for a thickness ratio of 0.1 and about 100 per cent for a ratio of 0.25.

Barlow's formula.—This formula assumes (1) that because of the elasticity of the material, the different circumferential fibers will have their diameters increased in

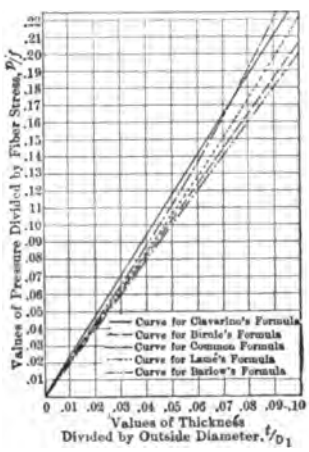

FIG. 13.

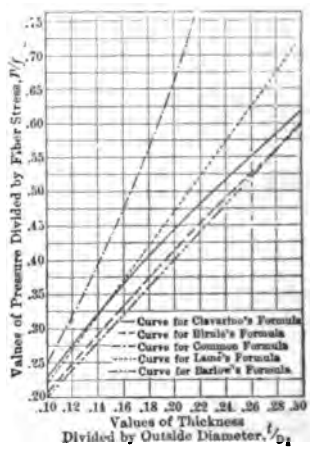

FIG. 14.

Comparison of internal fluid pressure formulae for tubes, pipes, and cylinders.

such a manner as to keep the area of cross-section constant, and (2) that the length of the tube is unaltered by the internal fluid pressure. As neither of these assumptions is theoretically correct, this formula can give only approximately correct results. Using the notation given above, this formula is

$$\frac{p}{f}=2\frac{t}{D_1};\quad p=2f\frac{t}{D_1};\quad t=\tfrac{1}{2}D_1\frac{p}{f};\quad f=\tfrac{1}{2}D_1\frac{p}{t}. \qquad (5)$$

It should be observed that while Barlow's formula is similar in form to the common formula, it gives results that are quite different when applied to tubes, pipes, and cylinders having walls of considerable thickness. This is due to the fact that Barlow's formula is expressed in terms of the outside diameter, D_1, whereas the common formula is expressed in terms of the inside diameter, D_2.

Referring to the curves, Figs. 13 and 14, it will be seen that Barlow's formula gives quite close results when used for the condition shown in Fig. 11, for which Birnie's formula is theoretically correct. The curves show for the entire practical range of thickness ratios that the error in values of $\frac{p}{f}$, for this case, does not exceed 3 per cent, the error throughout the whole practical range being on the side of safety. This, then, is the best of the simple theoretical formulae for application to the case illustrated in Fig. 11.

For the conditions shown in Fig. 12, namely, when the tube is subjected to the stresses due to an internal fluid pressure acting jointly on the tube wall and its closed ends, for which Clavarino's formula is theoretically correct, the curves show that Barlow's formula gives values of $\frac{p}{f}$ whose errors range from 15 per cent for tubes, pipes, and cylinders having thin walls to 10 per cent for those having thick walls, the error being on the side of safety for all practical thickness ratios.

Lamé's formula.—This formula is meant to apply to the conditions shown in Fig. 12. Each material particle of the tube wall is supposed to be subjected to the radial compression, and the circumferential and longitudinal tensions due to an internal fluid pressure acting jointly on the tube wall and its closed ends; and the material of the tube wall is supposed to be elastic under these actions. Lamé's formula, however, ignores the "coefficient of lateral contraction," known as "Poisson's ratio," and consequently is not theoretically correct.

Using the notation as given above, this formula is

$$\frac{p}{f}=\frac{D_1^2-D_2^2}{D_1^2+D_2^2};\quad p=\frac{D_1^2-D_2^2}{D_1^2+D_2^2}f;\quad D_2=D_1\sqrt{\frac{f-p}{f+p}};\quad D_1=D_2\sqrt{\frac{f+p}{f-p}}. \quad . \quad . \quad (6)$$

Referring to the curves, Figs. 13 and 14, it will be seen that Lamé's formula, which is meant to apply to the conditions for which Clavarino's formula is theoretically correct, gives for thickness ratios, $\frac{t}{D_1}$, less than 0.15, an error on the side of safety, the error having a maximum value of about 14 per cent when $\frac{t}{D_1}$ equals 0.01. For thickness ratios greater than 0.15 the error is on the side of danger, reaching 10 per cent for a ratio of about 0.23.

Clavarino's formula.—In this formula, as in Lamé's formula, each material particle of the tube wall is supposed to be subjected to the radial compression and the circumferential and longitudinal tensions due to an internal fluid pressure acting jointly on the tube wall and its closed ends; and the material is supposed to be elastic under these actions. Unlike Lamé's formula, however, this formula expresses the true stresses in the tube wall as based upon the "coefficient of lateral contraction," known as "Poisson's ratio," and is consequently theoretically correct for the conditions shown in Fig. 12, providing the stress on the most strained fiber does not exceed the elastic limit of the material.

Using the notation given above and assuming the value of the "coefficient of lateral contraction," for tube steel to be 0.3, this formula is

$$\frac{p}{f}=\frac{10(D_1^2-D_2^2)}{13D_1^2+4D_2^2};\quad p=\frac{10(D_1^2-D_2^2)}{13D_1^2+4D_2^2}f;\quad D_1=D_2\sqrt{\frac{10f+4p}{10f-13p}};$$

$$D_2=D_1\sqrt{\frac{10f-13p}{10f+4p}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

This theoretically correct formula for the conditions shown in Fig. 12 has the dis-

advantage that it is difficult to apply directly in making calculations. In order to remove this difficulty the table on page 717 has been prepared, by means of which any desired calculation can be as readily made by Clavarino's formula as by any of the simpler formulae. The entries of this table are the values in Clavarino's formula of the factor

$$\frac{10(D_1^2-D_2^2)}{13D_1^2+4D_2^2}=k.$$

It will be observed that these factors are tabulated for thickness ratios, $\frac{t}{D_1}$, from 0.01 to 0.3, advancing by thousandths. Thus for a wall thickness, t, of 0.25 inch and an outside diameter, D_1, of 10 inches, the thickness ratio, $\frac{t}{D_1}$, would be 0.25 divided by 10, or 0.025. The required factor corresponding to this thickness ratio is 0.0587 and is found in the column headed 0.005 opposite 0.02 in column one. Similarly for an outside diameter of 4 inches and a wall thickness of 0.5 inch the thickness ratio would be 0.125 and the corresponding internal pressure factor is 0.2869.

If we designate the value of any tabular factor by k, then it is obvious that Clavarino's formula may be written

$$\frac{p}{f}=k;\quad p=kf;\quad f=\frac{p}{k}. \qquad (8)$$

This table is well adapted to the ready solution of problems involving the strength and safety of a tube, pipe, or cylinder which is subjected to the stresses due to an internal fluid pressure acting jointly on its wall and closed ends, as illustrated in Fig. 12.

Problem 1.—*Required the safe working fluid pressure* p, Fig. 12, when the outside diameter, D_1, equals 4 inches; thickness of wall, t, equals 0.5 inch; and the working fiber stress of the steel, f, equals 10,000 pounds.

Solution.—(1) The thickness ratio, $\frac{t}{D_1}$, equals 0.125; (2) the corresponding tabular factor, k, is found from the table, page 717, to be 0.2869; and (3) the required safe working fluid pressure, p, equals kf (equation 8), or 0.2869 times 10,000, or 2869 pounds per square inch.

Problem 2.—*Required the fiber stress*, f, in the wall of a cylinder, Fig. 12, when the outside diameter, D_1, equals 5.5 inches; the thickness of wall, t, equals 0.25 inch; and the working fluid pressure, p, equals 1500 pounds per square inch.

Solution.—(1) The thickness ratio, $\frac{t}{D_1}$, equals 0.045; (2) the corresponding tabular factor, k, is found from table on page 717, to be 0.1054; and (3) the required fiber stress, f, equals $\frac{p}{k}$ (equation 8), or 1500 divided by 0.1054, or 14,200 pounds per square inch.

Problem 3.—*Required the thickness of wall*, t, Fig. 12, when the outside diameter, D_1, equals 8 inches; the working fiber stress of the steel, f, equals 15,000 pounds per square inch; and the working fluid pressure, p, equals 2000 pounds per square inch.

Solution.—(1) The factor, k, equals $\frac{p}{f}$ (equation 8) or 2000 divided by 15,000 or 0.133; (2) the value of the thickness ratio, $\frac{t}{D_1}$, corresponding to this value of k is found from the table on page 717 to be 0.057; and (3) the required thickness will result from

Comparison of Internal Fluid Pressure Formulae for Tubes, Pipes and Cylinders
Internal Fluid Pressure Factors, k, for Conditions Shown in Fig. 12

[Calculated by Clavarino's formula, assuming for steel a "coefficient of lateral contraction" (Poisson's ratio) equal 0.3.]

Rule.—Divide thickness of tube or pipe by its outside diameter, both being expressed in inches, then multiply the tabular value corresponding to this quotient by the working fiber stress in pounds per square inch. The result will be the safe internal pressure in pounds per square inch.

For further use of table, see page 16.

t/D_1	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.01	0.0235	0.0259	0.0282	0.0306	0.0329	0.0352	0.0376	0.0399	0.0423	0.0446
.02	.0470	.0493	.0517	.0540	.0564	.0587	.0610	.0634	.0657	.0681
.03	.0704	.0727	.0751	.0774	.0797	.0821	.0844	.0867	.0891	.0914
.04	.0937	.0961	.0984	.1007	.1031	.1054	.1077	.1100	.1123	.1147
.05	.1170	.1193	.1216	.1239	.1263	.1286	.1309	.1332	.1355	.1378
.06	.1401	.1424	.1448	.1471	.1494	.1517	.1540	.1563	.1586	.1609
.07	.1632	.1655	.1678	.1700	.1723	.1746	.1769	.1792	.1815	.1838
.08	.1861	.1883	.1906	.1929	.1952	.1974	.1997	.2020	.2043	.2065
.09	.2088	.2111	.2133	.2156	.2178	.2201	.2223	.2246	.2269	.2291
.10	.2314	.2336	.2358	.2381	.2403	.2425	.2448	.2470	.2493	.2515
.11	.2537	.2559	.2582	.2604	.2626	.2648	.2670	.2692	.2715	.2737
.12	.2759	.2781	.2803	.2825	.2847	.2869	.2890	.2912	.2934	.2956
.13	.2978	.3000	.3022	.3043	.3065	.3087	.3108	.3130	.3152	.3173
.14	.3195	.3216	.3238	.3259	.3281	.3302	.3323	.3345	.3366	.3388
.15	.3409	.3430	.3451	.3472	.3494	.3515	.3536	.3557	.3578	.3599
.16	.3620	.3641	.3662	.3683	.3704	.3724	.3745	.3766	.3787	.3808
.17	.3828	.3849	.3869	.3890	.3910	.3931	.3951	.3972	.3992	.4013
.18	.4033	.4053	.4073	.4094	.4114	.4134	.4154	.4174	.4194	.4214
.19	.4234	.4254	.4274	.4294	.4314	.4333	.4353	.4373	.4393	.4412
.20	.4432	.4452	.4471	.4490	.4510	.4529	.4548	.4568	.4587	.4606
.21	.4626	.4645	.4664	.4683	.4702	.4721	.4740	.4758	.4777	.4796
.22	.4815	.4834	.4852	.4871	.4889	.4908	.4926	.4945	.4964	.4982
.23	.5001	.5019	.5037	.5055	.5073	.5091	.5109	.5127	.5145	.5163
.24	.5181	.5199	.5216	.5234	.5252	.5269	.5287	.5304	.5322	.5340
.25	.5357	.5374	.5391	.5408	.5426	.5443	.5460	.5477	.5494	.5511
.26	.5528	.5545	.5561	.5578	.5594	.5611	.5628	.5644	.5661	.5677
.27	.5694	.5710	.5726	.5742	.5758	.5774	.5790	.5806	.5822	.5838
.28	.5854	.5870	.5885	.5901	.5916	.5932	.5947	.5963	.5978	.5991
.29	.6009	.6024	.6039	.6054	.6069	.6084	.6099	.6114	.6129	.6143
.30	.6158	.6173	.6187	.6201	.6216	.6230	.6244	.6259	.6273	.6287

Internal Fluid Pressure Factors, k, for Conditions Shown in Fig. 12

[Calculated by Birnie's formula, assuming for steel a "coefficient of lateral contraction" (Poisson's ratio) equal 0.3.]

Rule.—Divide thickness of tube or pipe by its outside diameter, both being expressed in inches, then multiply the tabular value corresponding to this quotient by the working fiber stress in pounds per square inch. The result will be the safe internal pressure in pounds per square inch.

For further use of table, see page 719.

t/D_1	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.01	0.0201	0.0221	0.0241	0.0261	0.0282	0.0302	0.0322	0.0342	0.0363	0.0383
.02	.0403	.0423	.0444	.0464	.0485	.0505	.0525	.0546	.0566	.0586
.03	.0607	.0627	.0648	.0668	.0689	.0709	.0730	.0750	.0771	.0791
.04	.0812	.0832	.0853	.0873	.0894	.0915	.0935	.0956	.0976	.0997
.05	.1018	.1038	.1059	.1080	.1100	.1121	.1142	.1163	.1183	.1204
.06	.1225	.1245	.1266	.1287	.1308	.1329	.1349	.1370	.1391	.1412
.07	.1433	.1453	.1474	.1495	.1516	.1537	.1558	.1579	.1599	.1620
.08	.1641	.1662	.1683	.1704	.1725	.1746	.1767	.1787	.1808	.1829
.09	.1850	.1871	.1892	.1913	.1934	.1955	.1976	.1997	.2018	.2039
.10	.2059	.2080	.2101	.2122	.2143	.2164	.2185	.2206	.2227	.2248
.11	.2269	.2290	.2311	.2332	.2353	.2374	.2395	.2416	.2437	.2457
.12	.2478	.2499	.2520	.2541	.2562	.2583	.2604	.2625	.2646	.2667
.13	.2688	.2708	.2729	.2750	.2771	.2792	.2813	.2834	.2854	.2875
.14	.2896	.2917	.2938	.2959	.2979	.3000	.3021	.3042	.3062	.3083
.15	.3104	.3125	.3145	.3166	.3187	.3208	.3228	.3249	.3270	.3290
.16	.3311	.3332	.3352	.3373	.3393	.3414	.3434	.3455	.3476	.3496
.17	.3517	.3537	.3558	.3578	.3598	.3619	.3639	.3660	.3680	.3700
.18	.3721	.3741	.3761	.3782	.3802	.3822	.3842	.3863	.3883	.3903
.19	.3923	.3943	.3963	.3983	.4003	.4024	.4044	.4064	.4084	.4104
.20	.4124	.4144	.4163	.4183	.4203	.4223	.4243	.4262	.4282	.4302
.21	.4322	.4341	.4361	.4380	.4400	.4419	.4439	.4459	.4478	.4498
.22	.4517	.4536	.4556	.4575	.4594	.4613	.4633	.4652	.4671	.4690
.23	.4710	.4729	.4748	.4767	.4785	.4804	.4823	.4842	.4861	.4880
.24	.4899	.4918	.4936	.4955	.4973	.4992	.5010	.5029	.5048	.5066
.25	.5085	.5103	.5121	.5139	.5157	.5176	.5194	.5212	.5230	.5248
.26	.5266	.5284	.5302	.5320	.5338	.5355	.5373	.5391	.5409	.5427
.27	.5444	.5462	.5479	.5496	.5514	.5531	.5548	.5566	.5583	.5600
.28	.5617	.5634	.5651	.5668	.5685	.5702	.5718	.5735	.5752	.5769
.29	.5786	.5802	.5818	.5835	.5851	.5867	.5884	.5900	.5916	.5933
.30	.5949	.5965	.5981	.5996	.6012	.6028	.6044	.6059	.6075	.6091

multiplying this thickness ratio, $\frac{t}{D_1}$, by the outside diameter, D_1, or 0.057 times 8 equals 0.456 inch.

NOTE.—When the inside diameter, D_2; the internal pressure, p; and the working fiber stress, f, are given and it is required to find the thickness of wall, t: proceed by finding first the value of the outside diameter, D_1, by means of equation (7), after which the required thickness may be had by taking one-half the difference of the outside and inside diameters, or

$$t=\frac{D_1-D_2}{2}. \qquad (9)$$

Birnie's formula.—This formula is based upon the conditions illustrated in Fig. 11. In its derivation, precisely the same assumptions are made as for Clavarino's formula with the single exception that the longitudinal stress, f_l, due to the internal fluid pressure acting upon attached heads is assumed not to exist. Birnie's formula consequently is theoretically correct for tubes, pipes, and cylinders that are subjected to an internal fluid pressure in such a manner as not to give rise to longitudinal stress in the wall; provided the stress on the most strained fiber does not exceed the elastic limit of the material.

Using the same notation as before and assuming the value of the "coefficient of lateral contraction" for steel to be 0.3, this formula is

$$\frac{p}{f}=\frac{10(D_1^2-D_2^2)}{13D_1^2+7D_2^2}; \quad p=\frac{10(D_1^2-D_2^2)}{13D_1^2+D_2^2}f; \quad D_1=D_2\sqrt{\frac{10f+7p}{10f-13p}};$$

$$D_2=D_1\sqrt{\frac{10f-13p}{10f+7p}}. \qquad (10)$$

Birnie's formula, like Clavarino's formula, has the disadvantage of being difficult to apply directly in making calculations. In order to remove this difficulty the table on page 718 has been prepared, the entries being the values in Birnie's formula of the factor

$$\frac{10(D_1^2-D_2^2)}{13D_1^2+7D_2^2}=k.$$

This table is used in a manner precisely similar to the table of factors for Clavarino's formula. See explanation and solution of problems on page 716.

STRENGTH OF COMMERCIAL TUBES, PIPES AND CYLINDERS TO RESIST INTERNAL FLUID PRESSURES

In the preceding portion of this chapter there appears a full statement of the basis of each of the five theoretical formulae for the strength of tubes, pipes, and cylinders when subjected to internal fluid pressures, together with a comparison of results obtained by their use. One or other of these formulae, taken apparently at random, has often been used without sufficient understanding of their application to practical conditions. It is the purpose of what follows to illustrate the proper application of these formulae making use of the results of hydrostatic tests recently made on commercial pipes at one of the mills of the National Tube Company.

Yield point tests on commercial pipe.—Tests were made under Clavarino's condition, Fig. 12, on 195 specimens of 10-inch and 279 specimens of 12-inch lap-welded steel pipes, all of which were made up into cylinders with heads welded to the pipe. The hydrostatic pressure was raised until the yield point of the material was reached.

The unit stresses on the most strained fibers were then calculated by means of Clavarino's formula, the pipes having been measured by micrometer, before welding in the head, to determine the least thickness of wall.

The average results of the yield points of the most strained fibers of the material constituting these pipes when compared with the average yield point of tensile test specimens cut from about 400 similar pipes may be summarized as follows:

Outside diameter of pipe, inches	10.00	12.00
Least thickness of wall, inch	.172	.164
Hydrostatic pressure at yield point, pounds per square inch	1,435	1,195
Yield point by Clavarino's formula, pounds per square inch	35,600	37,100
Yield point, average of tensile tests, pounds per square inch	37,000	37,000
Apparent error in yield point by Clavarino's formula	−3.8%	+0.3%

This summary of the average results of 474 tests is a very satisfactory confirmation of the accuracy of Clavarino's formula when applied to commercial steel pipes for the conditions under which the formula theoretically applies.

Other tests show that when the heads are attached to the pipe, as in Fig. 12, it lengthens upon application of an internal fluid pressure, and that when the heads are held independently, as in Fig. 11, it shortens in accord respectively with the assumptions which constitute the basis of Clavarino's and Birnie's formulæ regarding change of length under internal fluid pressure.

Applicability of Clavarino's and Birnie's formulae.—The above summary of results of tests on pipes shows that Clavarino's formula is applicable to commercial wrought steel pipe for the condition shown in Fig. 12, when the yield point of the most strained fiber is not exceeded and the least thickness of wall is accurately known.

Tests made at the Watertown Arsenal in 1892–3–4–7 and 1902 on sections of steel guns show that Birnie's formula for the condition shown in Fig. 11, when applied up to the elastic limit of the most strained fiber, gives results which agree with the results of direct tests that are within the ordinary range of experimental error. These Watertown Arsenal tests were all made on tubes the material and dimensions of which were uniform to a degree obtainable only by boring and turning from forgings of the choicest portion of selected ingots.

It is apparent that any variation below the nominal or average value in strength of material, thickness of wall and efficiency of joint in welded pipe, or above the nominal in diameter, will give results which err on the side of danger when making use of either Clavarino's or Birnie's formulae. These formulae then should be restricted in their use to certain classes of seamless tubes and cylinders and to critical examinations of ordinary tubes, pipes and cylinders, when exact results are desired and sufficiently accurate data are available.

For all ordinary calculations of strength of commercial tubes, pipes and cylinders Barlow's simple approximate formula is preferable.

Bursting tests of commercial tubes and pipes.—The tables, page 722, show the average results of several hundred tests of commercial tubes and pipes, all of which were burst by hydrostatic pressure at one of the mills of the National Tube Company.

Of the steel tubes and pipes, 95 per cent were made by this company, while 86 per cent of the wrought-iron pipe tested was obtained by purchase in the open market.

The average ultimate tensile strength of pipe steel is 57,000 pounds per square inch, whether taken in the direction of rolling or transversely thereto, while that of the

seamless steel tested is 60,000 pounds per square inch. No tensile tests were made of the material of the wrought-iron pipes.

An examination of these tables leads to the following general conclusions:

1. In commercial welded pipe the variations in thickness of wall, perfection of weld, etc., give rise to variations in bursting strength of sufficient magnitude to render unnecessary any consideration of Clavarino's or Birnie's condition of head support as shown in Figs. 12 and 11 respectively.

2. The relative strengths of steel pipes and tubes, when using Barlow's formula and basing the calculations on average diameter, thickness of wall and ultimate tensile strength of material, are as follows: For butt-welded steel pipe, 73 per cent; for lap-welded steel pipe, 92 per cent; and for seamless steel tubes, approximately 100 per cent.

In steel pipe, then, the strength of the butt-weld is about 80 per cent of that of the lap-weld.

3. The relative strengths of wrought-iron and steel pipe, from the accompanying tables, are as follows: Butt-welded wrought-iron pipe is 70 per cent as strong as similar butt-welded steel pipe; and lap-welded wrought iron pipe is 50 per cent as strong as similar lap-welded steel pipe.

Applicability of Barlow's formula.—Of the five formulae considered in this chapter that by Barlow is the best suited for all ordinary calculations pertaining to the bursting strength of commercial tubes, pipes and cylinders.

The theoretical error on the side of safety resulting from its use will generally not exceed the actual combined error on the side of danger when using either Birnie's or Clavarino's formula due to the ordinary range of variation in the thickness of wall, strength of the material, etc., when applied to the ordinary commercial product.

This is true, at least up to the yield point of the material for any ratio or thickness of wall to outside diameter less than three-tenths. In this respect Barlow's formula is very superior to the common approximate formula which gives errors that are absurdly large on the side of danger for very thick walls. See Fig. 14.

For certain classes of seamless tubes and cylinders and for critical examinations of welded pipe, where the least thickness of wall, yield point of material, etc., are known with accuracy, and close results are desired, see Clavarino's formula and Birnie's equations (7) and (10).

For all ordinary calculations pertaining to the bursting strength of commercial tubes, pipes and cylinders use Barlow's formula, which is

$$\frac{p}{f}=2\frac{t}{D};\quad p=2f\frac{t}{D};\quad t=\tfrac{1}{2}D\frac{p}{f};\quad f=\tfrac{1}{2}D\frac{p}{t},$$

where D = outside diameter, inches;
t = average thickness of wall, inches;
p = internal fluid pressure, pounds per square inch;
f = working or safe fiber stress, pounds per square inch;
when n = safety factor as based on ultimate strength then
$f = 40{,}000/n$ for butt-welded steel pipe;
$= 50{,}000/n$ for lap-welded steel pipe;
$= 60{,}000/n$ for seamless steel tubes;
$= 28{,}000/n$ for wrought iron pipe.

These average values of f are based upon the accompanying tables of bursting tests of commercial tubes and pipes. They are intended for substitution in Barlow's formula in case more exact data for the working fiber stress are not at hand.

Bursting Tests of Commercial Tubes and Pipes

(Test made by National Tube Company)

Size		Number of pieces burst	Nominal external diameter, inches	Average thickness of walls, inch	Bursting Pressures (pounds per square inch) Minimum	Maximum	Average	Head condition	See note below	Average fiber stress by Barlow's formula	Class of material
Steel—butt-welded	1/8	10	0.405	0.066	11,840	17,320	14,266	*C*	1	44,011	Standard pipe
	1/4	10	.540	.085	8,830	14,680	12,206	*C*	1	38,645	Standard pipe
	3/8	10	.675	.088	5,850	13,030	10,330	*C*	1	39,272	Standard pipe
	1/2	10	.840	.101	11,380	16,310	14,038	*C*	0	58,163	Standard pipe
	3/4	10	1.050	.109	7,150	9,150	8,020	*C*	0	38,657	Standard pipe
	1	10	1.315	.131	4,500	8,800	6,990	*C*	0	35,085	Standard pipe
	1¼	10	1.660	.139	4,400	7,300	5,808	*C*	0	34,603	Standard pipe
	1¼	15	1.660	.140	5,500	11,900	7,700	*C*	1	45,215	Redrawn
	1½	10	1.900	.143	3,000	6,100	4,960	*C*	0	33,031	Standard pipe
	2	11	2.375	.149	3,830	6,060	4,951	*C*	0	40,485	Standard pipe
	2½	10	2.875	.198	4,310	5,740	5,134	*C*	0	37,351	Standard pipe
	3	10	3.500	.204	4,650	6,370	5,398	*C*	0	46,234	Standard pipe
	1¼	10	1.660	.180	7,910	14,280	10,514	*C*	0	48,922	Extra strong
	2	10	2.375	.213	7,250	8,940	8,238	*C*	0	45,935	Extra strong
	2	10	2.375	.220	6,160	8,920	7,661	*C*	0	41,347	Extra strong
	2	10	2.375	.445	8,500	18,314	14,992	*C*	0	40,023	XX strong
						General average				41,686	
Steel—lap-welded	2	10	2.375	.155	4,890	7,940	6,645	*C*	1	50,962	Standard pipe
	2	10	2.375	.182	4,860	10,060	7,361	*C*	0	47,889	Standard pipe
	3	10	3.500	.210	3,830	8,200	6,368	*C*	7	53,560	Standard pipe
	4	10	4.500	.232	4,810	5,680	5,249	*C*	1	51,462	Standard pipe
	5	10	5.563	.258	3,410	5,260	4,538	*C*	1	48,882	Standard pipe
	6	5	6.625	.275	2,450	5,210	4,088	*C*	0	49,286	Standard pipe
	6	5	6.625	.275	3,170	4,760	3,666	*B*	0	44,106	Standard pipe
	10	5	10.750	.349	3,560	4,730	4,290	*C*	1	66,080	Standard pipe
	10	5	10.750	.347	2,770	3,940	3,396	*B*	2	52,692	Standard pipe
	2	10	2.375	.218	2,500	9,870	7,909	*C*	0	43,254	Extra strong
	2	10	2.000	.108	5,100	6,560	6,062	*C*	7	55,607	Boiler tubes
	3	10	3.000	.112	3,220	4,860	3,967	*C*	1	52,957	Boiler tubes
	4	5	4.000	.135	3,640	4,070	3,840	*C*	2	56,978	Boiler tubes
	4	5	4.000	.136	3,720	4,040	3,914	*B*	1	57,440	Boiler tubes
						General average				52,225	
Steel—Seamless	2	10	2.000	.098	5,420	6,590	6,052	*C*	10	61,530	Boiler tubes
	3	10	3.000	.112	3,940	4,730	4,272	*C*	10	57,075	Boiler tubes
	4	6	4.000	.134	4,160	4,440	4,318	*C*	6	64,450	Boiler tubes
	4	4	4.000	.134	4,250	4,440	4,328	*B*	4	64,488	Boiler tubes
						General average				61,886	
Iron—butt-welded	1¼	10	1.660	.136	2,880	6,290	5,283	*C*	3	32,126	Standard pipe
	1¼	10	1.660	.136	3,640	5,680	4,891	*C*	1	29,817	Standard pipe
	2	10	2.375	.156	2,930	4,250	3,687	*C*	2	28,051	Standard pipe
	1¼	10	1.660	.188	2,770	7,330	5,895	*C*	1	26,678	Extra strong
						General average				29,168	
Iron—lap-welded	2	10	2.375	.152	2,400	3,940	3,213	*C*	1	25,122	Standard pipe
	2	10	2.375	.207	5,530	7,120	6,349	*C*	8	36,461	Extra strong
						General average				30,792	

The column marked "See note below" gives the number burst by failure of material not at weld.

***C*—Clavarino conditions, Fig. 12. *B*—Birnie conditions, Fig. 11.**

Strength of Weld of Commercial Tubes and Pipes
(Selected from Preceding Table of Bursting Tests)

Size	Number burst in weld *	Average fiber stress by Barlow's formula	Class of material
Steel—Butt-welded			
1/8	9	43,938	Standard pipe
1/4	9	37,777	Standard pipe
3/8	9	38,954	Standard pipe
1/2	10	58,163	Standard pipe
3/4	10	38,657	Standard pipe
1	10	35,085	Standard pipe
1 1/4	10	34,603	Standard pipe
1 1/4	14	45,643	Redrawn
1 1/2	10	33,031	Standard pipe
2	11	40,485	Standard pipe
2 1/2	10	37,351	Standard pipe
3	10	46,234	Standard pipe
1 1/4	10	48,922	Extra strong
2	10	45,935	Extra strong
2	10	41,347	Extra strong
2	10	40,023	XX strong
General average		41,634	
Steel—Lap-welded			
2	9	50,052	Standard pipe
2	10	47,889	Standard pipe
3	3	54,510	Standard pipe
4	9	51,019	Standard pipe
5	9	48,852	Standard pipe
6	10	47,026	Standard pipe
10	7	59,537	Standard pipe
2	10	43,254	Extra strong
2	3	56,933	Boiler tubes
3	9	51,980	Boiler tubes
4	7	57,521	Boiler tubes
General average		51,688	
Iron—Butt-welded			
1 1/4	7	31,136	Standard pipe
1 1/4	9	30,680	Standard pipe
2	8	27,323	Standard pipe
1 1/4	9	27,073	Extra strong
General average		29,053	
Iron—Lap-welded			
2	9	24,581	Standard pipe
2	2	34,340	Extra strong
General average		29,461	

* These only are included in averages.

Internal Fluid Pressures for Standard Pipe

(Based on Barlow's formula $P = 2f\frac{t}{D}$)

D = outside diameter in inches.
t = thickness of wall in inches.

P = pressure in pounds per square inch.
f = fiber stress in pounds per square inch.

Size	External diameter	Thickness	Ultimate Bursting Pressure: Butt-weld, Fiber stress 40,000 lbs. per sq. in.	Ultimate Bursting Pressure: Lap-weld, Fiber stress 50,000 lbs. per sq. in.	Factor of safety = 5: Butt-weld fiber stress = 8000 lbs. per sq. in.	Factor of safety = 5: Lap-weld fiber stress = 10000 lbs. per sq. in.	Factor of safety = 6: Butt-weld fiber stress = 6667 lbs. per sq. in.	Factor of safety = 6: Lap-weld fiber stress = 8333 lbs. per sq. in.	Factor of safety = 8: Butt-weld fiber stress = 5000 lbs. per sq. in.	Factor of safety = 8: Lap-weld fiber stress = 6250 lbs. per sq. in.	Factor of safety = 10: Butt-weld fiber stress = 4000 lbs. per sq. in.	Factor of safety = 10: Lap-weld fiber stress = 5000 lbs. per sq. in.
1/8	0.405	0.068	13,432	......	2686	......	2239	......	1679	......	1343	......
1/4	.540	.088	13,037	......	2607	......	2173	......	1630	......	1304	......
3/8	.675	.091	10,785	......	2157	......	1798	......	1348	......	1079	......
1/2	.840	.109	10,381	......	2076	......	1730	......	1298	......	1038	......
3/4	1.050	.113	8,610	......	1722	......	1435	......	1076	......	861	......
1	1.315	.133	8,091	......	1618	......	1340	......	1011	......	809	......
1¼	1.660	.140	6,747	8434	1349	1687	1124	1406	843	1054	675	843
1½	1.900	.145	6,105	7632	1221	1526	1018	1272	763	954	611	763
2	2.375	.154	5,187	6484	1037	1297	865	1081	648	811	519	648
2½	2.875	.203	5,649	7061	1130	1412	941	1177	706	883	565	706
3	3.500	.216	4,937	6171	987	1234	823	1029	617	771	494	617
3½	4.000	.226	......	5650	......	1130	......	942	......	706	......	565
4	4.500	.237	......	5267	......	1053	......	878	......	658	......	527
4½	5.000	.247	......	4940	......	988	......	823	......	618	......	494
5	5.563	.258	......	4638	......	928	......	773	......	580	......	464
6	6.625	.280	......	4226	......	845	......	704	......	528	......	423
7	7.625	.301	......	3948	......	790	......	658	......	493	......	395
8	8.625	.277	......	3212	......	642	......	535	......	401	......	321
8	8.625	.322	......	3733	......	747	......	622	......	467	......	373
9	9.625	.342	......	3553	......	711	......	592	......	444	......	355
10	10.750	.279	......	2595	......	519	......	433	......	324	......	260
10	10.750	.307	......	2856	......	571	......	476	......	357	......	386
10	10.750	.365	......	3395	......	670	......	566	......	424	......	240
11	11.750	.375	......	3191	......	638	......	532	......	399	......	319
12	12.750	.330	......	2588	......	518	......	431	......	324	......	259
12	12.750	.375	......	2941	......	588	......	490	......	368	......	294
13	14.000	.375	......	2679	......	536	......	446	......	335	......	268
14	15.000	.375	......	2500	......	500	......	417	......	313	......	250
15	16.000	.375	......	2344	......	469	......	391	......	293	......	234
16 O. D.	17.000	.393	......	2312	......	462	......	385	......	289	......	231
17 O. D.	18.000	.409	......	2272	......	454	......	379	......	284	......	227
19 O. D.	20.000	.409	......	2045	......	409	......	341	......	256	......	205

Internal Fluid Pressures for Extra Strong Pipe

(Based on Barlow's formula $P = 2f\frac{t}{D}$)

D = outside diameter in inches.
t = thickness of wall in inches.

P = pressure in pounds per square inch.
f = fiber stress in pounds per square inch.

Size	External diameter	Thickness	Ultimate Bursting Pressure		Pressures at Various Factors of Safety							
			Butt-weld	Lap-weld	Factor of safety = 5		Factor of safety = 6		Factor of safety = 8		Factor of safety = 10	
			Fiber stress 40,000 lbs. per sq. in.	Fiber stress 50,000 lbs. per sq. in.	Butt-weld fiber stress = 8000 lbs. per sq. in.	Lap-weld fiber stress = 10000 lbs. per sq. in.	Butt-weld fiber stress = 6667 lbs. per sq. in.	Lap-weld fiber stress = 8333 lbs. per sq. in.	Butt-weld fiber stress = 5000 lbs. per sq. in.	Lap-weld fiber stress = 6250 lbs. per sq. in.	Butt-weld fiber stress = 4000 lbs. per sq. in.	Lap-weld fiber stress = 5000 lbs. per sq. in.
1/8	0.405	0.095	18,765	......	3753	......	3128	......	2346	......	1877	......
1/4	.540	.119	17,630	......	3526	......	2938	......	2204	......	1763	......
3/8	.675	.126	14,933	......	2987	......	2489	......	1867	......	1493	......
1/2	.840	.147	14,000	......	2800	......	2333	......	1750	......	1400	......
3/4	1.050	.154	11,733	......	2347	......	1956	......	1467	......	1173	......
1	1.315	.179	10,890	......	2178	......	1815	......	1361	......	1089	......
1¼	1.660	.191	9,205	11,506	1841	2301	1534	1918	1151	1438	920	1151
1½	1.900	.200	8,421	10,526	1684	2105	1404	1754	1053	1316	842	1053
2	2.375	.218	7,343	9,179	1469	1836	1224	1530	918	1147	734	918
2½	2.875	.276	7,680	9,600	1536	1920	1280	1600	960	1200	768	960
3	3.500	.300	6,857	8,571	1371	1714	1143	1429	857	1071	686	857
3½	4.000	.318	......	7,950	......	1590	......	1325	......	994	......	795
4	4.500	.337	......	7,489	......	1498	......	1248	......	936	......	749
4½	5.000	.355	......	7,100	......	1420	......	1183	......	888	......	710
5	5.563	.375	......	6,741	......	1348	......	1124	......	843	......	674
6	6.625	.432	......	6,521	......	1304	......	1087	......	815	......	652
7	7.625	.500	......	6,557	......	1311	......	1093	......	820	......	656
8	8.625	.500	......	5,797	......	1159	......	966	......	725	......	580
9	9.625	.500	......	5,195	......	1039	......	866	......	649	......	519
10	10.750	.500	......	4,651	......	930	......	775	......	581	......	465
11	11.750	.500	......	4,255	......	851	......	709	......	532	......	426
12	12.750	.500	......	3,922	......	784	......	654	......	490	....	392
13	14.000	.500	......	3,571	......	714	......	595	......	446	......	357
14	15.000	.500	......	3,333	......	667	......	556	......	417	......	333
15	16.000	.500	......	3,125	......	625	......	521	......	391	......	313

Internal Fluid Pressures for Double Extra Strong Pipe

(Based on Barlow's formula $P = 2f\frac{t}{D}$)

D = outside diameter in inches.
t = thickness of wall in inches.

P = pressure in pounds per square inch.
f = fiber stress in pounds per square inch.

Size	External diameter	Thickness	Ultimate Bursting Pressure		Pressures at Various Factors of Safety							
			Butt-weld	Lap-weld	Factor of safety = 5		Factor of safety = 6		Factor of safety = 8		Factor of safety = 10	
			Fiber stress 40,000 lbs. per sq. in.	Fiber stress 50,000 lbs. per sq. in.	Butt-weld fiber stress = 8000 lbs. per sq. in.	Lap-weld fiber stress = 10000 lbs. per sq. in.	Butt-weld fiber stress = 6667 lbs. per sq. in.	Lap-weld fiber stress = 8333 lbs. per sq. in.	Butt-weld fiber stress = 5000 lbs. per sq. in.	Lap-weld fiber stress = 6250 lbs. per sq. in.	Butt-weld fiber stress = 4000 lbs. per sq. in.	Lap-weld fiber stress = 5000 lbs. per sq. in.
½	0.840	0.294	28,000	......	5600	......	4667	......	3500	......	2800	......
¾	1.050	.308	23,467	......	4693	......	3911	......	2933	......	2347	......
1	1.315	.358	21,779	......	4356	......	3630	......	2722	......	2178	......
1¼	1.660	.382	18,410	......	3682	......	3068	......	2301	......	1841	......
1½	1.900	.400	16,842	21,053	3368	4211	2807	3509	2105	2632	1684	2105
2	2.375	.436	14,686	18,358	2937	3672	2448	3060	1836	2295	1469	1836
2½	2.875	.552	15,360	19,200	3072	3840	2560	3200	1920	2400	1536	1920
3	3.500	.600	......	17,143	......	3429	......	2857	......	2143	......	1714
3½	4.000	.636	......	15,900	......	3180	......	2650	......	1988	......	1590
4	4.500	.674	......	14,978	......	2996	......	2496	......	1872	......	1498
4½	5.000	.710	......	14,200	......	2840	......	2367	......	1775	......	1420
5	5.563	.750	......	13,482	......	2696	......	2247	......	1685	......	1348
6	6.625	.864	......	13,042	......	2608	......	2174	......	1630	......	1304
7	7.625	.875	......	11,475	......	2295	......	1913	......	1434	......	1148
8	8.625	.875	......	10,145	......	2029	......	1691	......	1268	......	1014

Internal Fluid Pressures for Standard Boiler Tubes and Flues—Lap-Welded

(Based on Barlow's formula $P = 2f\frac{t}{D}$)

D = outside diameter in inches.
t = thickness of wall in inches.
P = pressure in pounds per square inch.
f = fiber stress in pounds per square inch.

External diameter	Thickness		Ultimate bursting pressure	Pressures at Various Factors of Safety			
				Factor of safety = 5	Factor of safety = 6	Factor of safety = 8	Factor of safety = 10
	Inches	B. W. G.	Fiber stress = 50,000 lbs. per sq. in.	Fiber stress = 10,000 lbs. per sq. in.	Fiber stress = 8333 lbs. per sq. in.	Fiber stress = 6250 lbs. per sq. in.	Fiber stress = 5000 lbs. per sq. in.
$1\frac{3}{4}$	0.095	13	5429	1086	905	679	543
2	.095	13	4750	950	792	594	475
$2\frac{1}{4}$	.095	13	4222	844	704	528	422
$2\frac{1}{2}$	.109	12	4360	872	727	545	436
$2\frac{3}{4}$	.109	12	3964	793	661	495	396
3	.109	12	3633	727	606	454	363
$3\frac{1}{4}$	.120	11	3692	738	615	462	369
$3\frac{1}{2}$	.120	11	3429	686	571	429	343
$3\frac{3}{4}$	.120	11	3200	640	533	400	320
4	.134	10	3350	670	558	419	335
$4\frac{1}{2}$	.134	10	2978	596	496	372	298
5	.148	9	2960	592	493	370	296
6	.165	8	2750	550	458	344	275
7	.165	8	2357	471	393	295	236
8	.165	8	2063	413	344	258	206
9	.180	7	2000	400	333	250	200
10	.203	6	2030	406	338	254	203
11	.220	5	2000	400	333	250	200
12	.229	....	1908	382	318	239	191
13	.238	4	1831	366	305	229	183
14	.248	....	1771	354	295	221	177
15	.259	3	1727	345	288	216	173
16	.270	....	1688	338	281	211	169

Correct Pipe Threading Principles[1]

Certain fundamental principles govern the results obtained in threading pipe which should interest and do concern practically everyone who has anything to do with the threading of pipe.

Whether pipe is threaded by power machines or by hand-operated tools, when trouble is experienced the cause can usually be attributed to dull or blunt dies, improperly designed dies or to poor lubrication.

Failure to study the fundamental principles of pipe threading sometimes results in placing the blame for poor threads on the material in the pipe, when the trouble can often be traced to the use of dies that have not been kept in working condition, or to dies of antiquated design.

It frequently happens that an individual or firm possesses an equipment of dies of improperly designed type, which are not giving satisfaction, and cannot economically or conveniently be discarded.

The following points are set forth for the benefit of pipe fitters engaged in commercial practice, using either hand-operated tools or power machines to thread pipe,

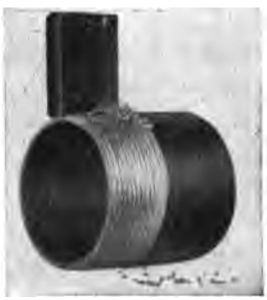

Fig. 15.—Rough thread cut with old-style chaser. Note crumbling chips.

Fig. 16.—Clean, strong thread cut with properly designed chaser. Note spiral chips.

as distinguished from pipe manufacturers engaged in mill practice where all sizes of pipe up to 20-inch are threaded on power machines under the most ideal conditions.

Commercial practice.—To secure good threaded joints it is necessary to have clean, smoothly cut threads of the proper taper and pitch; and to secure such threads it is necessary to have threading dies made with full consideration for the following points:

> Lip, chip space, clearance, lead, oil; and, in the case of power machines, number of chasers.

These points are taken up below and explained separately, beginning with

Lip.—To clearly illustrate what is meant by lip on a chaser, two photographs are shown. One of them (Fig. 15) shows an old type of chaser which has no lip, and the other (Fig. 16) shows a modern type of power machine chaser which has a lip milled or ground in the cutting face. As will be seen, the lip forms a slanted cutting edge on the chaser which allows the chips to curl off clean and leave a smooth thread. It also gives an easy cutting action to the chaser similar to that of a properly ground lathe tool instead of the pushing effect caused by chasers having no lip, and also permits considerable increase in cutting speed. The angle to which the lip should be ground on a chaser depends upon the kind of material to be threaded and the style and condition of the chasers and chaser holder. For ordinary steel pipe this angle should

[1] "Correct Pipe Threading Principles," Bull. No. 60. National Tube Co.

be from 15 to 20°, but chasers intended to cut open-hearth steel pipe should have a long, easy lip on account of the soft character of the material; for open-hearth steel the lip angle should be at least 25°. In all cases the back of the lip should be rounded to eliminate square corners or shoulders in which chips may catch and pack up. The different angles of lip for cutting different materials are shown in Figs. 17 and 18, while Fig. 19 shows how a chaser with practically no lip pushes the metal from the pipe in the form of crumbling chips.

There are many undesirable consequences of using chasers without proper lip. The extra power required to force them has a tendency to break out the teeth of the chaser

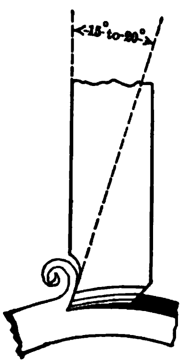

FIG. 17.

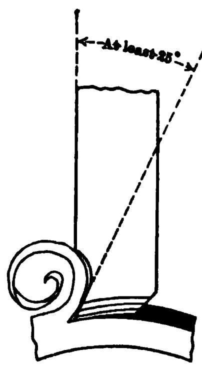

FIG. 18.

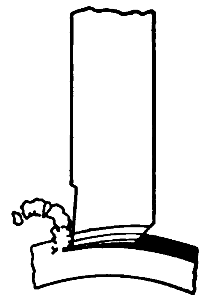

FIG. 19.

FIG. 17.—Chaser properly lipped for cutting ordinary Bessemer steel pipe.
FIG. 18.—Slightly increased angle of lip for cutting open-hearth steel pipe.
FIG. 19.—Insufficient lip angle. This type of chaser will push the metal off instead of cutting it.

which will then pick up "stickers," tearing the tops from the threads and creating unnecessary friction. While it is understood that all chasers should be ground to this style of lip, yet it is found that there are still some types of threading dies which are at variance with it. Cooperative measures between pipe manufacturers and the manufacturers of threading machinery and dies have resulted in considerable progress being made toward standardizing the principles outlined herein. The advisable thing to do when dies are found to be lacking in these essentials is to send them to the die manufacturer for the purpose of having a lip ground or machined on the chasers, or to turn them over to an experienced toolmaker, or to others making a specialty of this kind of work.

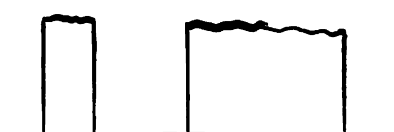

FIG. 20.—Chasers should have full lip across entire cutting face as shown. Depth should be same at *A* as at *B*.

The lip should be ground uniformly across the cutting face of the chaser (see Fig. 20) in order to obtain a full lip at all points. "Lip" is also commonly known as "hook" or "rake." The effect of lip is sometimes obtained by inclining the chasers in relation to the radial line of the pipe, as in Fig. 21, and in this instance the die is known as a "rake" die.

Chip space is the space required in the die holder in front of the chasers to prevent the accumulation or packing up of chips. The importance of this feature can not be too strongly emphasized, for, if sufficient chip space is not allowed, the chips

will rapidly pack in front of the chaser, causing rough, torn threads and creating a tendency on the part of the chaser to pick up stickers.

FIG. 21.—This shows a type of die known as the "rake" die, used in National Tube Company mills. The cutting edge is obtained by inclining the chaser instead of by cutting a lip, the effect being the same as secured with the lipped chaser. Clearance is obtained in this type by machining the chasers at a slightly greater angle than the position in which they are to work. Clearance may be obtained in this type of chaser by using the regular segment holder and machining the die on a smaller diameter than that of the pipe to be threaded.

Where no chip space is cut in the die ring, the chaser should project at least three-fourths of an inch beyond the ring, otherwise a clogging effect will be experienced. The best design for this chip space is shown in Figs. 22 and 23, where an even curve is provided for the chip to follow, while the back of each chaser is well supported.

This chip space is a particularly important consideration in dies used for cutting open-hearth steel pipe, as ample space is needed to care for the long, tough chip produced in threading this material (see Fig. 24, page 731). Absence of this feature in threading dies will cause difficulty in threading either Bessemer or open-hearth steel pipe. If proper consideration is given to lip and chip space, threading is done with less power and less friction, a better thread is obtained, broken teeth are prevented and the life of the die and its production are increased.

Clearance is the space between the threads of the chasers and the threads on the pipe. This clearance is secured by die manufacturers in various ways, and may be determined by certain effects produced by normal operation of the die. For example, the effect of ideal clearance in the threads of a chaser is shown in Fig. 25, which is a photograph of a chaser which has been used for some time. When this chaser was first set in the holder, the sides of the threads were uniformly dark in color, just as they were left after being

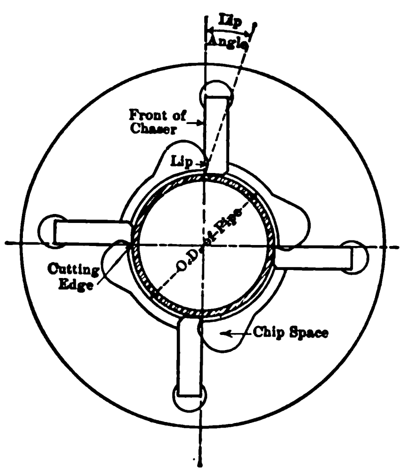

FIG. 22.—"Cutting-edge on center" type of chaser.

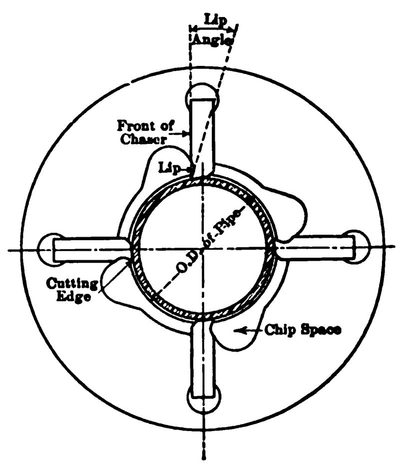

FIG. 23.—"Stock on center" type of chaser.

hardened and tempered. When the chaser had been in use for some time, the sides of the threads became polished, brighter at the cutting edge, and gradually shading almost to their original color at the back. The chaser of a die which shows this condi-

tion will work freely, cut clean (as shown by the chips in Fig. 16, page 728), will not tear the thread and will be durable. When the chasers of a die show a polish from the cutting edge to the back, there is a lack of clearance, causing the cutting edge to work hard, heat, and make rough, torn threads (as shown by the chips in Fig. 15).

Fig. 22 shows a die in which the chasers are set so that the cutting edge and the

FIG. 24a.

FIG. 24.

FIG. 24a.—From a photograph; showing the character and type of chips thrown off by a chaser of an old type.

FIG. 24.—From a photograph; showing the character and type of chips thrown off by a properly designed chaser.

front of the chaser are both on a radial line from the center of the die or pipe. A simple method used by die manufacturers for getting clearance in this type of die, known as "cutting-edge-on-center" or "center cut" is shown in Fig. 26, page 732, in which the chasers in the machining position are set out larger in diameter than when adjusted for cutting threads. Thus, in making a properly designed chaser for a 6-inch die, the chasers should be machined to about $\frac{7}{16}$ inch greater diameter. For a 4-inch die, $\frac{3}{8}$ inch, for a 2-inch die, $\frac{1}{4}$ inch, and for a 1-inch die, $\frac{3}{16}$ inch greater diameter; other sizes in the same proportion.

The effect of this is shown in exaggerated manner in Fig. 27, where it can be seen how the thread on the chaser, being cut to a slightly larger radius, gradually recedes from the thread on the pipe.

FIG. 25.—From a photograph of a properly designed chaser which had been in use for a considerable length of time.

Fig. 23 shows a die in which the chasers are set so that the cutting edge and front of the chaser cut ahead of the center, with the result that the center line of the die or pipe runs through or near the center of the chaser. Clearance may be obtained on this type of chaser by machining it in the same manner as a "cutting-edge-on-center" chaser. Proper clearance having been obtained, part of the "heel" can be ground off the back edge of the chaser. It is necessary to do this to prevent tearing the thread if the die must be backed off without opening.

Of course it is easy to go to extremes in these matters. If too much clearance is allowed, the result will be a wavy thread. Chasers with too much clearance and no heel usually cause chattering and its attendant troubles. Chasers with these faults are more susceptible to breakage than chasers which have been made with due consideration for the points mentioned.

The position in which the chaser shall be machined is determined by the position in which it is intended to work in relation to the pipe.

Lead or throat.—Lead is the angle which is machined or ground on the first three threads (more or less) of each chaser to enable the die to start on the pipe, and also to

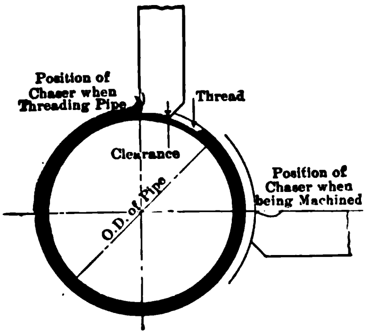

Fig. 26.

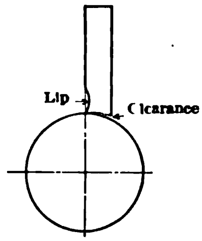

Fig. 27.

Fig. 26.—Method of machining "cutting-edge-on-center" chasers to secure proper clearance.
Fig. 27.—Showing clearance obtained by method in Fig. 26.

distribute the work of making the first cut over a number of threads. The lead may be machined on, or, as is more frequent, it may be ground on after the chasers are tempered. The proper amount of lead is about three threads. As the heaviest cutting is done by the lead it should have slightly greater clearance angle than the rest of the

Fig. 28.

Fig. 29.

Fig. 28.—Showing position of lipped type of chaser in relation to center line of grinding wheel. This view shows the correct position of chaser grinding table or rest.

Fig. 29.—This view shows the proper position in relation to the center line of grinding wheel for grinding the lead on a chaser of the "rake" type. Slightly greater clearance is required in this type of chaser because of its inclined working position when set in the die.

threads on the chaser, but care must be used to see that this angle is not excessive. Too much clearance here will cause the die to lead too fast, and the half threads cut by the lead are consequently damaged by the full teeth of the chasers.

Fig. 28 shows the position in which a lipped chaser should be held when

grinding the lead. An adjustable flat rest on the emery wheel stand is required, in order to position the chaser at the proper height to obtain the amount of clearance required.

Fig. 29 shows the position in which a chaser of the "rake" type (see also Fig. 21) should be held when grinding the lead or throat. An adjustable flat-top rest on the emery-wheel stand is also required when grinding this type of chaser—which, it will be noted, is ground at a higher position in relation to the horizontal center line of the wheel than is the lip type of chaser. The reason for this is that the teeth of the rake chaser are milled at a greater angle (higher at back of chaser) than on a lipped chaser, as the chaser must be set with "rake" (slanted) in the die instead of being set in alignment with the radial center line of the pipe. When set in the die with proper rake, the clearance in this type of chaser is substantially the same as in a lipped chaser,

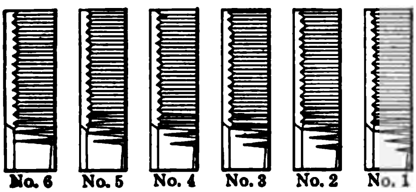

FIG. 30.—Correct arrangement of a set of chasers as to sequence of lead threads.

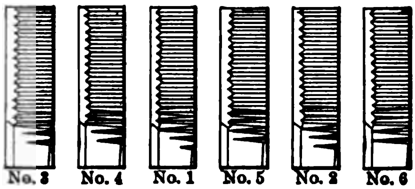

FIG. 31.—Incorrect arrangement of same chasers shown in Fig. 30.

but the point at the cutting edge of teeth or lead is much sharper than the point of an ordinary chaser before the latter is lipped; in view of this condition, care should be used in grinding the lead of a rake chaser to see that an excessive amount of clearance is not obtained, as such a condition would tend to weaken the chaser at the point where the heaviest cutting is done. The same applies to a lip chaser, especially if it has been lipped for cutting open-hearth steel pipe (the angle of lip being at least 25°, as compared to 15 to 20° on chasers used for cutting Bessemer steel).

In Fig. 30 is shown a set of tapered chasers with properly ground lead or throat. These are arranged in sequence, chaser No. 1 being at the right. It will be noticed how the first or lead thread gradually increases in size until from being a mere scratch on No. 1, it extends fully across chaser No. 6. This set of chasers will cut smoothly, each one doing its share of the work, and the chips will come off cleanly and evenly. Fig. 31 shows a set of chasers with the lead or throat incorrectly ground, for, as will be seen, the lead thread on one chaser does not correspond to those preceding or following.

The effect of this would be to distribute the work unevenly, causing the chasers which do the most work to become dull, and making it difficult for the die to take hold when starting to cut a thread. It is this improperly ground lead which also makes a die let go after being fairly well started, spoiling the thread and dulling the chaser.

A perfectly good set of chasers can be ruined by improperly regrinding the lead. Fig. 32 shows the proper and improper methods of regrinding the lead. Note carefully that the proper method is to regrind parallel to the original lead, as shown by the heavy lines. Care should be taken to see that all chasers are ground at the same angles. The improper methods commonly used are shown by dotted lines.

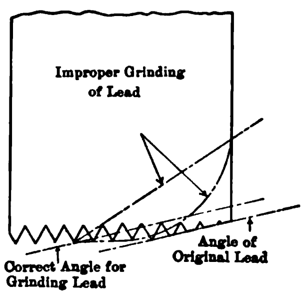

FIG. 32.—Correct angle for regrinding lead of chasers.

Number of chasers.—To get good results in threading at one cut, experience shows that a die should have a suitable number of chasers, the approximate number being determined by the size of the die. Experience of The National Tube Company on power machines shows that dies up to 1¼ inches should have at least four chasers; 1½ to 4 inches should have at least six; 4½ to 8 inches should have at least eight; and 9 to 12 inches should have at least twelve chasers. The number of chasers necessarily depends upon the design, size, and operative principle of the die, hence no exact rule can be laid down for universal acceptance. When an insufficient number of chasers is used, the die will chatter and cut a rough thread.

Oil.—Care should be taken in the quality of oil used, as the best die made will not produce good results with poor or insufficient oil.

For use on hand tools or where the flow is intermittent, No. 1 lard oil can be used with success, as cottonseed oils have a tendency to gum up if not used in a constant flow.

Experience of experts shows that the very best lard oil is the best lubricant. Cheap lubricant is destructive to dies, and more power is required to perform work when it is used.

A mixture particularly adapted to power machines where there is a steady flow of

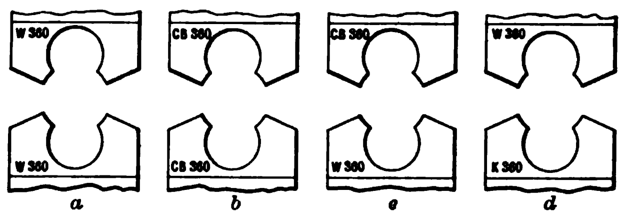

FIG. 33.

Two sets of chasers (*a* and *b*) properly arranged in pairs according to serial numbers and letter.

Improperly arranged sets of chasers. The serial numbers show that the chasers belong to three different sets of dies.

lubricant, which will give good results, and is comparatively inexpensive, is composed of 50 per cent cottonseed oil and 50 per cent light neutral oil.

There are several cutting oils on the market at the present time which are giving satisfactory results and are recommended to those who have experienced difficulty in securing their accustomed lubricants or have found the preparation of special mixtures unprofitable or inconvenient.

Care and repair of dies.—To get the best results with the dies now made, the user should bear in mind certain rules promulgated by the die manufacturer.

Where a die of two or more chasers is used, care should be used to see that the letter and number of each chaser corresponds, as all chasers in a die set have both the same letter and number; for instance, W360 or CB360. A chaser marked W360 would not operate satisfactorily with a chaser from another die set marked CB360. If chasers from two or more separate sets are used in one die, the lead threads may not follow in proper order, and the troubles mentioned on page 733, in connection with Fig. 31, will be experienced. In many cases it has been found that only the *number* of a chaser has been noted and no attention has been paid to the serial *letter*, and as a consequence the pipe and die have both been condemned, first, the pipe for being hard to cut, and second, the die for being defective. Diagrams *a*, *b*, *c*, *d*, Fig. 33, show correct and incorrect combinations of chasers. When chasers are placed in holder, care should be taken to have them set at equal distances from center of holder. Chasers set "out of center" will generally cut an imperfect thread.

Proper grinding of chasers.—Manufacturers of threading dies find that chasers received from customers as defective or to be reground show signs of having been abused and carelessly ground. Much of this trouble could have been eliminated if the users had returned them to the manufacturers for regrinding in the first place or had observed the following simple rules, issued by a large dealer [1] in dies:

1. Be careful not to burn the dies in grinding.
2. Do not grind too much at one time.
3. Be careful where you grind and how you grind.

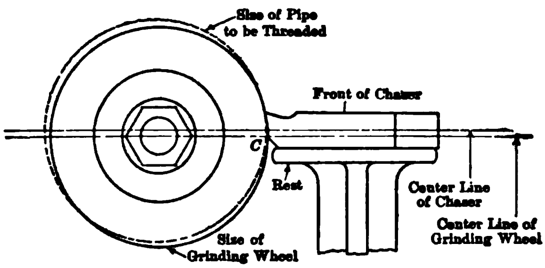

FIG. 34.—Proper method of grinding chasers to secure clearance in lead or throat. The chaser is raised or lowered according as the design of the die requires. *C* indicates the amount of clearance which will be obtained. See also Figs. 28 and 29.

Some types of old dies can often be improved by grinding a lip with proper cutting angle and otherwise altering the chasers to make them as close as possible in design to the type shown in Fig. 16, page 728.

Proper clearance on lead is very important. Care should be taken to have just sufficient clearance in the throat to have a good cutting edge, as too much clearance will weaken the chaser at the point where the heaviest duty is required of the chaser. Fig. 34 shows the approximately correct position for grinding a "stock-on-center" chaser to secure proper clearance on lead. The chaser in this case should be held in a perfectly horizontal position, the back of the chaser being a little below the center of

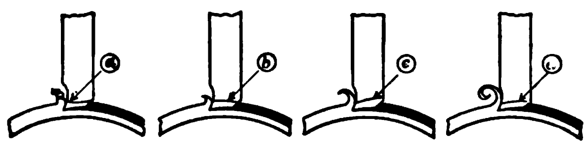

FIG. 35.—(*a*) Cutting edge rounded off. No clearance in lead. Result of careless grinding and lack of temper in steel of chaser. (*b*) No clearance in throat or lead. (*c*) Too much clearance in throat or lead. (*d*) Correct throat or lead.

the grinding wheel, which, for purpose of illustration, is shown as about the same diameter as that of the pipe. Greater clearance may be obtained by slightly raising the rest. When a grinding wheel somewhat larger than the diameter of the pipe is used, the center of the chaser should be slightly above the center of the wheel. The clearance may be reduced by lowering the rest, but the chaser should always be held perfectly horizontal unless a specially designed jig or fixture is used to hold the chaser at correct grinding angle.

If precaution is not taken to hold the chaser firmly on the rest or in a suitable jig, or to see that the metal does not become overheated, the result is likely to be a burnt tool with the cutting edge rounded off or having no temper (see diagram *a*, Fig. 35).

[1] Crane Company.

Diagram *b*, Fig. 35, shows the result of grinding the lead at too low a point on the wheel (assuming that the chaser has been held horizontally); this chaser has no clearance on throat or lead and is subject to excessive friction when working which the best lubricant can not overcome.

Diagram *c*, Fig. 35, shows the opposite extreme—the result of grinding the chaser at too high a position in relation to the center of the grinding wheel. This leaves too much clearance in the lead and as a consequence the lip is weakened at that point and the die will chatter causing a rough wavering thread, if not in fact stripping short pieces from the threads, or breaking the chaser.

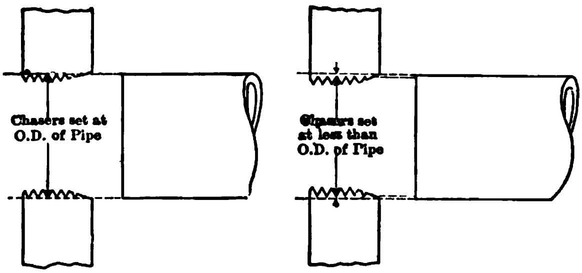

FIG. 36.—Showing proper and improper depth of chasers as set in die stock.

Diagram *d*, Fig. 35, shows a chaser ground with proper lead clearance. A careful study of all four diagrams in Fig. 35 will reveal wherein *d* is the correct form for cutting good strong threads. These diagrams are shown simply for the purpose of comparison, and do not represent exact measurements to be used as a working basis.

Care should also be taken to see that the chasers are not set too deep in the stock. That is, the diameter between oppositely disposed chasers at the greatest permissible cutting depth of chaser threads should not be less than the outside diameter of the

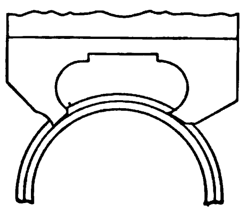

FIG. 37.

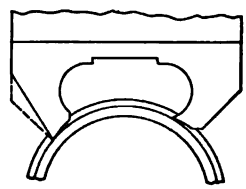

FIG. 38.

FIG. 37.—Heel removed to prevent tearing of threads when backing off the die from pipe.

FIG. 38.—Dotted line shows ordinary cutting angle. Black line shows proper angle or rake of die; dies so ground will cut pipe threads with less effort than those which have not been so angled.

pipe. Pipe fitters are quite apt to be satisfied that the chasers are properly set so long as the lead is sufficient to allow easy starting of the die, but it frequently happens that the chaser is set too deep, and the die is literally forced on the pipe after passing the first two or three threads of the chaser. This results in stripping the top off the threads, sometimes the whole thread, overheating and ruining of the die, especially when a tough material is threaded. If any discrimination is to be made, it should be on the side of a light, clean cut rather than a deep cut that is forced (see Fig. 36).

A careful study of Figs. 37, 38, and 39 will be of value. The illustrations with their appended data are self-explanatory.

In " backing off " a solid die, where a common hand stock is used, care should be

taken to see that the chaser does not jump the thread channel, causing cross threading or stripping. This is particularly apt to happen when backing the die off the last few threads (the first threads cut on the pipe).

Regrinding broken teeth of chasers.—It is always better to grind out of a chaser, with a thin emery wheel, a tooth which has become broken, as the rough portion, if allowed to remain, is likely to pick up a sticker and tear the thread on the pipe.

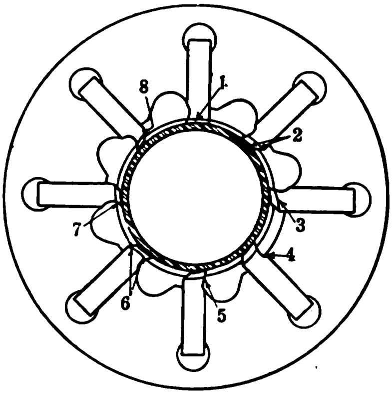

Fig. 39.—Lead or throat too flat.[1]

If the chaser picks up a sticker, it is very important that the broken tooth which caused the trouble be ground out. If the sticker is removed by digging and the broken tooth is not ground out, the trouble will occur again at the same spot. When a chaser picks up a sticker on an important occasion such as a break-down job, or on a pipe which has been cut after being bent, the consequences are particularly disagreeable and costly.

It is surprising how many teeth may be ground out of a set of chasers without impairing its usefulness. Fig. 40 shows an extreme example. This set of chasers was removed from a die in a machine where they were producing first-class work; they were later returned to the same machine and continued to do good work. Grinding out the teeth of chasers to this extent is not recommended as good practice, but these examples serve to illustrate the increased life and service that may be obtained by careful treatment of chasers.

Fig. 40.—The teeth in these chasers were ground out to illustrate that even excessive grinding at times if properly done, does not make a chaser useless. These chasers will cut good threads, though the use of chasers in this condition is not recommended. It will be noticed that there are no broken, ragged teeth to pick up stickers and tear the top off the threads. These illustrations also show very clearly the grinding of the heel, a precaution neccessary to prevent tearing the threads, when backing off a die that can not be opened before removing from pipe.

Old chasers with dull and rusted threads may be resharpened with emery and oil. If too dull, they may be rehobbed.

[1] Fig. 39.—Lead or throat too flat; cutting edge rounded off by careless grinding. 2. Proper clearance in lead and threads of chaser. 3. Too much clearance in lead. 4. No chip space; note sharp corner where chips may lodge, pile up, and break threads. 5. Proper lead and chip space but not sufficient cutting angle of lip. 6. Lead too high on cutting edge and back, due to careless grinding; chaser should be held perfectly horizontal and rigid, or in a special jig while grinding lead. 7. Lip is incorrectly ground; cutting edge is too thin and sharp, has too great an angle and will quickly overheat or break off. 8. Too much of heel has been removed; a chaser ground this way will give an imperfect, wavering thread.

The chip space shown in the die head is correct in all cases except that in front of chaser No. 4.

Chasers in receding types of dies may be rehobbed and the lead reground to cut the next larger size of pipe.

Proper threading principles as affecting receding type of threading dies.—The principles of correct lip, chip space, clearance, lead or throat, etc., apply in equal measure to both that type of die which consists of a number of chasers held stationary in the die, and to that type wherein the chasers are movable and gradually recede from the pipe as the thread is cut. It will be readily seen why these principles apply in both cases when it is considered that the principal difference in the design of the chasers is that those which are held stationary are tapered to correspond to the taper of the thread to be cut on the pipe, while the receding type are practically straight and cut the thread to the required taper by gradually moving backward, removing less and less stock as the cutting of the thread progresses. The principles of lip, chip space, clearance, etc., are therefore seen to be principles which affect the cutting action of chasers regardless of the operative principle of the particular dies of which they form a part. A receding die would push the metal off instead of cutting it, in the same manner as a solid die of poor design, if its chasers were not properly lipped and other proper threading principles were ignored. Happily, the modern type of receding die is not designed with the principle of pushing the metal off, but is in reality a lathe tool.

That the chasers of the modern receding type of die are designed on the principle of a lathe tool (being narrower than the "solid" or tapered type of chaser) is additional

FIG. 41.—On the right is shown a set of chasers of the type usually furnished with threading machines. The flat cutting edge obstructs the ready cutting of the material, and no groove is provided for the chips to follow. On the left is shown a set of chasers of the same type; on these, however, a lip has been ground which allows the chips to curl off clean and leave a smooth thread, at the same time giving an easy cutting action to the chaser and removes the pushing effect which obtains with the flat chasers which do not have a lip. Clearance is obtained in these chasers by the same method used for other dies of the "stock-on-center" type. (See Figs. 26 and 27.)

reason why proper clearance and lip or rake should be maintained and the best of lubricant used.

Chasers of this type which have become damaged or dulled in use should be returned to the die manufacturer for repairs, unless the attention of expert toolmakers or other specialists in this work can be given them. The efficiency of the receding type of die is well indicated by the fact that it is frequently used to thread pipe by hand up to 12 inches diameter.

Mill practice.—That pipe up to 20-inch diameter is threaded at the mill with power machines, whereas the local fitter employs both hand-operated tools and power machines for threading pipe ⅛ to 6 inches and, on certain occasions, pipe up to 12 inches diameter, indicates that there is not a pronounced difference between commercial and mill practice. The chief difference lies in the fact that the manufacturer of pipe has

better facilities than the average shop for keeping dies in working condition or for altering their design slightly for certain purposes—for instance, increasing the lip angle of the chasers for cutting open hearth steel, regrinding lead of chasers which have become dull through use, and making other minor changes.

Cutting speeds of power machines affect the quality of threads and the life and efficiency of the chaser. If the speed is too great the metal is torn away instead of being cut, the chaser is overheated and a ragged thread results. To attain high cutting speed, it is necessary to have an ample continuous flow of lubricant to wash away the cuttings and to keep the chasers clean and sufficiently cold to do the work properly.

The special factors of good pipe threading, such as lip, chip space, clearance, etc., of chasers, apply equally to mill practice and commercial practice. These subjects have been treated under their respective heads on pages 728 to and 731 those interested in these points of mill practice arc referred to the pages mentioned. In this general connection the information regarding the number of chasers listed on page 734 is supplemented by the following:

Dies up to 1¼ inches should have at least 4 chasers;
1½ to 4 inches should have at least 6 chasers;
4½ to 8 inches should have at least 8 chasers;
9 to 12 inches should have at least 12 chasers;
13 to 16 inches should have at least 14 chasers;
17 to 20 inches should have at least 16 chasers.

Summary.—A die which is made with due regard to all the points enumerated will thread pipe of any uniform material with good results; steel pipe is naturally soft and tough, and consequently somewhat more difficult to thread with the old form of die shown in Fig. 15, page 728. This chaser pushes the metal off or tears it up. A good shape is shown in Fig. 16, page 728, which has sufficient rake and clearance to cut the metal with a clean finish without waste of power or unnecessary friction, similar to the working of a lathe tool, which latter principle is embodied in some of the modern threading tools.

The importance and value of the characteristic principles of properly designed threading dies, particularly those of lip, angle and clearance, cannot be overestimated. Unless these are correct it will be found difficult to obtain satisfactory threading results. Practical experience, careful study and experiment have determined these principles.

Applying these principles to hand dies it is possible for one man to do the work of two. In a paper by T. N. Thompson, read before The American Society of Heating and Ventilating Engineers, are described certain tests on the power required to thread pipe with hand dies of the common pattern [1] and with the same type of dies correctly made. The author says:

"It shows that the power required to thread mild-steel pipe with the new die is not much more than that required to thread wrought iron with the same die, and much less than the power required to thread wrought-iron pipe with the common die."

Sizes of Pipe—Briggs' Standard

The nominal sizes of pipe 10 inches and under, and the pitches of the threads, were for the most part established in the British tube (called "pipe" in America) trade between 1820 and 1840. The sizes are designated roughly, according to their internal diameters.

Robert Briggs, about 1862, while Superintendent of the Pascal Iron Works, formulated the nominal dimensions of pipe up to and including 10 inches. These dimensions have been broadly spread and are widely known as "Briggs' Standard." They are as follows:

[1] Full width—non-receding.

The nominal and outside diameters and pitch of thread, for sizes 10 inches and under.[1]

The following table is a compilation of the results obtained by using the formula, $L=\frac{0.8D+4.8}{n}$, as given above.

"National" pipe size	Number of threads per inch	Nominal total length of thread on "National" pipe	"National" pipe size	Number of threads per inch	Nominal total length of thread on "National" pipe
$\frac{1}{8}$	27	$\frac{3}{8}$	5	8	$1\frac{13}{16}$
$\frac{1}{4}$	18	$\frac{9}{16}$	6	8	$1\frac{7}{8}$
$\frac{3}{8}$	18	$\frac{9}{16}$	7	8	2
$\frac{1}{2}$	14	$\frac{3}{4}$	8	8	$2\frac{1}{16}$
$\frac{3}{4}$	14	$\frac{3}{4}$	9	8	$2\frac{3}{16}$
1	$11\frac{1}{2}$	$\frac{15}{16}$	10	8	$2\frac{5}{16}$
$1\frac{1}{4}$	$11\frac{1}{2}$	$\frac{15}{16}$	11	8	$2\frac{3}{8}$
$1\frac{1}{2}$	$11\frac{1}{2}$	1	12	8	$2\frac{1}{2}$
2	$11\frac{1}{2}$	$1\frac{1}{8}$	14 O. D.	8	$2\frac{5}{8}$
$2\frac{1}{2}$	8	$1\frac{1}{2}$	15 O. D.	8	$2\frac{3}{4}$
3	8	$1\frac{9}{16}$	16 O. D.	8	$2\frac{13}{16}$
$3\frac{1}{2}$	8	$1\frac{5}{8}$	17 O. D.	8	$2\frac{15}{16}$
4	8	$1\frac{11}{16}$	18 O. D.	8	3
$4\frac{1}{2}$	8	$1\frac{3}{4}$	20 O. D.	8	$3\frac{1}{4}$

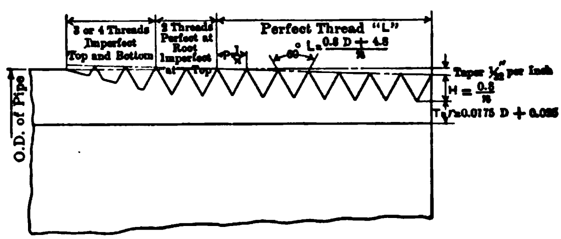

FIG. 42.—The Briggs standard thread.

The thread has an angle of 60° and is slightly rounded off at top and bottom so that the total height (depth), $H=\frac{0.8}{n}$, where n is the number of threads per inch.

The pitch of the threads $\left(\frac{1}{n}\right)$ increases roughly with the diameter, but in an arbitrary and irregular manner. It would be advantageous to change the pitches except for the fact that they are now firmly established.

The conically threaded ends of pipe are cut at a taper of $\frac{3}{4}$ inch diameter per foot of length (i. e., 1 in 32 to the axis of the pipe). (See Fig. 42.)

The thread is perfect for a distance (L) from the end of the pipe, expressed by the rule, $L=\frac{0.8D+4.8}{n}$; where D=outside diameter in inches. Then come two threads,

[1] Book of Standards, pages 208–209, 1917 Edition, National Tube Company.

perfect at the root or bottom, but imperfect at the top, and then come three or four threads imperfect at both top and bottom. These last do not enter into the joint at all, but are incident to the process of cutting the threads.

The thickness of the pipe under the root of the thread at the end of the pipe equals $T = 0.0175D + 0.025$ inch.

The above notes on Briggs' Standard were taken from Paper No. 1842, "American Practice in Warming Buildings by Steam," presented before the British Institute of Civil Engineers by Robert Briggs, member of the Institute. It is contained in the Institute Proceedings, Vol. LXXI, Session 1882–83, Part I. The substance of that paper is quoted quite fully in the report of the Committee on Standard Pipe and Pipe Threads to the American Society of Mechanical Engineers at the seventh annual meeting and is published in Vol. VIII, Paper No. 226, of their proceedings. The report was accepted by the American Society, December 29, 1886.

Briggs' Standard was adopted by the manufacturers of wrought-iron pipe and boiler tubes, October 27, 1886, and indorsed by the Manufacturers' Association of Brass and Iron, Steam, Gas and Water Works, December 8, 1886; except that the outside diameter of 9-inch pipe was changed to 9.625 inches.

By trade usage, the above rules have been extended to take in sizes up to 15 inches inclusive, except that the standard thickness is 0.375 inch, with the outside diameters given. Pipes larger than 12 inches, nominal size, are known by their outside diameter. The dimensions have also been extended to extra strong and double extra strong pipe, by holding the outside diameter and allowing the inside diameter to decrease according to increase in thickness.[1]

The following table gives the depth of different pipe and casing threads:

8 threads per inch	0.100 inch
10 threads per inch	.080 inch
11½ threads per inch	.0696 inch
14 threads per inch	.0571 inch
18 threads per inch	.0444 inch
27 threads per inch	.0296 inch

Lubrication of threaded joints.—In order to prevent galling, careful attention should be given to the proper lubrication of joints before screwing on either in the shop or in the field. Before a joint is made up in the field the threads should be thoroughly cleaned free from sand or dirt, and coated with a well-mixed threading "dope" or lubricant. The following mixtures have proved satisfactory for this purpose.

Lubricant for Threaded Joints

	Per cent
Tallow	33.4
White lead	23.2
Graphite	2.9
Neutral oil	40.5

or

	Pounds
Sylvan number 2 cup grease	100
Sterling white lead	35
Ground graphite	8

Galling is caused by some portions of the metal of the threads coming together under great pressure so that portions of the male and female threads practically unite. The result is a torn or stripped thread. Care in threading and thorough lubrication

[1] Book of Standards, 1917 Edition, National Tube Company.

will go far towards eliminating this trouble. Special non-galling couplings are now made which have less tendency to stick to the pipe.

Trade Customs and Mill Practice of National Tube Company

1. All weights are figured on the basis of 1 cubic inch of steel weighing .2833 pound and iron 2 per cent less.

2. All material will be cut to length when so ordered, with extreme variation not exceeding ⅛ inch over or under, unless otherwise arranged.

3. All pipe is threaded to American (Briggs') standard.

4. In ordering, desired weight or thickness, but not both, should be designated.

5. All weights given in the tables are limited to three decimal places.

6. The outside diameter of all classes of pipe, casing, tubing, tubes, etc., heavier than standard, is the same outside diameter as standard, the extra thickness always being on the inside.

7. Pipe and tubing are known and spoken of by their nominal inside diameters from ⅛ inch to 12 inches, inclusive. Casing is known by its nominal inside diameter.

8. Above 12 inches inside diameter, pipe and tubing are always known and spoken of by their outside diameters, and when ordering, thickness desired must be specified.

9. All dimensions of tubular materials are subject to change without notice.

10. For illustrations showing joints see pages 686 to 693, 752 and 756.

11. On orders calling for commercial sizes of pipe which are finished with threads and couplings, in sizes ⅛ inch to 12 inches inclusive, and where orders specify quantity in lineal feet, it is understood that random lengths fitted with threads on both ends and coupling on one end will be shipped and the measurement is charged from end to end, that is, over-all including coupling.

If cut lengths of any size are ordered instructions must appear on the face of the order whether plain ends, threads only, or threads and couplings are required. The mill then cuts the pipe proper to the length specified for plain ends and threads only, but if cut lengths with threads and couplings are specified, the practice is the same with the exception that the couplings are charged separately, whether they are shipped loose or screwed on the pipe. On larger sizes; namely, 14 inch "O. D." and larger, information must appear on the order as to whether plain ends, threads only, or threads and couplings are required, inasmuch as these large sizes are customarily held in stock in plain ends, subject to order as to the necessary requirements in regard to threads only or threads and couplings.

In figuring on lineal feet of pipe required for laying long lines, customer should make allowance when figuring on pipe fitted with threads and couplings for the distance that pipe is screwed into coupling when assembling in the field—the customary allowance being one-half the length of the coupling.

Specification for Standard Welded Pipe[1]

1. **Material.**—Welded pipe is to be made of uniformly good quality soft weldable steel rolled from solid ingots. Sufficient crop shall be cut from the ends to insure sound material, and the steel shall be given the most approved treatment in heating and rolling.

2. **Process of manufacture.**—All pipe shall be made either by the lap or butt-weld process as specified on order according to the best methods and practice.

3. **Surface inspection.**—The pipe must be reasonably straight and free from blisters, cracks or other injurious defects. Liquor marks incidental to the manufacture of lap-welded pipe will not be considered as surface defects. The pipe shall not vary more than 1 per cent either way from being perfectly round or true to the standard outside

[1] National Tube Company, November 1, 1911. Specification No. 1

diameter, except on the small sizes where a variation of $\frac{1}{64}$ inch will be accepted. The pipe must not vary more than 5 per cent either way from standard weight.

4. **Threading and reaming.**—Where required, the pipe must have a good Briggs' standard thread, which will make a tight joint when tested by hydraulic pressure at the mill. The thread must not vary more than $1\frac{1}{2}$ turns either way when tested with an American standard working gage. All burrs at the ends are to be removed.

5. **Internal pressure test.**—The following test pressures will be applied to the respective sizes of standard butt- and lap-weld pipe as indicated in table:

Test Pressures for Standard Pipe

Nominal size	Method of manufacture	Test pressure, pounds
$\frac{1}{8}$ inch to 2 inches (inclusive)	Butt-weld	700
$2\frac{1}{2}$ inches and 3 inches	Butt-weld	800
Up to 8 inches	Lap-weld	1000
9 and 10 inches	Lap-weld	900
11 and 12 inches	Lap-weld	800
13 and 14 inches	Lap-weld	700
15 inch	Lap-weld	600

On 8, 10 and 12-inch sizes which have more than one weight as standard, the hydraulic test pressure is shown for the heaviest weight.

6. **Testing of material.**—The steel from which the pipe is made must show the following physical properties:

Physical Tests for Steel for Pipes

Tensile strength	Over 50,000 pounds
Elastic limit	Over 30,000 pounds
Elongation in 8 inches	18 per cent
Reduction in area	50 per cent

A test piece cut lengthwise from the pipe and filed smooth on the edges should bend through 180° with an inner diameter at the bend equal to the thickness of the material, without fracture.

7. **Couplings.**—The material to be sound and free from injurious defects. Threads must be clean-cut, tapped straight through and of such pitch diameter as will make a tight joint. The ends must be countersunk.

8. **Thread protection.**—Solid tapped rings or split couplings will be provided as thread protectors on all sizes 4 inches in diameter or larger. Protection will be provided for smaller sizes when specifically called for on order.

9. All tests shall be made at mill.

Standard Specifications for "National" Line Pipe[1]

1. **Process.**—(*a*) The steel shall be of soft weldable quality made by the Bessemer process. (*b*) All line pipe manufactured under these specifications shall be lap-welded.

2. **Chemical composition.**—The steel shall conform to the following requirements as to chemical composition:

[1] National Tube Company Bessemer Line Pipe Specification, No. 1-C, April 1, 1919, Superseding Specification No. 1-B, October 1, 1916.

Chemical Composition for Steel for Pipes

	Per Cent
Carbon	Not over 0.09
Manganese	0.30 to 0.60
Phosphorus	Not over 0.10
Sulphur	Not over 0.06

3. **Ladle analyses.**—An analysis of each melt of steel shall be made by the manufacturer to determine the percentage of carbon and manganese and an analysis of each tenth melt to determine the percentages of phosphorus and sulphur. These analyses shall be made from test ingots taken during the pouring of the melts. The chemical composition thus determined shall be reported to the purchaser or his representative if required, and shall conform to the requirements specified in the previous paragraph.

4. **Check analysis.**—An analysis may be made by the purchaser from a broken tension test specimen representing each melt.

The phosphorus and sulphur content thus determined shall not exceed that specified in paragraph 2 by more than 25 per cent.

5. **Tension tests.**—(*a*) The material shall conform to the following minimum requirements as to tensile properties:

Tensile strength, pounds per square inch	50,000
Yield point, pounds per square inch	30,000
Elongation in 8 inches, per cent	20

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

6. **Hydrostatic tests.**—All pipe shall be tested at the mill to the hydrostatic pressures specified in the following table:

Hydrostatic Pressures for Pipe

Nominal size	Test pressure, pounds per square inch
2½ and 3 inches	1800
3½ inches	1700
4 and 4½ inches	1600
5 and 6 inches	1500
7 inches	1200
8 inches (25.414 pounds per foot)	1000
8 inches (29.213 pounds) and 9 inches (34.612 pounds)	1200
10 inches (32.515 pounds)	800
10 inches (35.504 pounds)	900
10 inches (41.644 pounds)	1000
11 inches	900
12 inches (45.217 pounds)	800
12 inches (50.916 pounds)	900
13, 14, 15 and 17 inches O. D.	750
18 inches O. D.	700
20 inches O. D.	650

7. **Flattening test.**—A section of pipe not less than 4 inches long cut from the ends of each length of pipe shall be flattened between parallel plates until the distance between the plates is $\frac{1}{3}$ the outside diameter of the pipe without showing cracks or opening at the weld. The test shall be made with the weld at 45° from the point of maximum bend. If any section fails another piece may be cut; should the second test fail, the pipe shall be rejected.

8. **Test specimens.**—(*a*) Tension test specimens shall be taken longitudinally from the finished pipe. They shall be of the full thickness of material, and may be machined to the form and dimensions shown in Fig. 1, A. S. T. M. Standards, 1918, or with both edges parallel. The specimen shall not be flattened before testing. (*b*) The sections cut for flattening test may be machined on the ends to remove burrs.

9. **Number of tests.**—(*a*) One tension test may be made from a pipe in each lot of 200 or less, of each size. Each length shall be subjected to the hydrostatic and flattening test specified in paragraphs 6 and 7. (*b*) If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted. (*c*) If the percentages of elongation of any tension test specimen is less than that specified in paragraph 5 (*a*) and any part of the fracture is outside the middle third of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

10. **Retests.**—If the results of the physical tests of any lot do not conform to the requirements specified in paragraph 5, retests of two additional pipes shall be made, each of which shall conform to the requirements specified.

11. **Permissible variations in size, weight and length.**—(*a*) The outside diameter shall not vary more than 1 per cent over or under the standard size. (*b*) The weight of the pipe shall not vary more than 5 per cent over or under that specified. (*c*) The lengths of the pipe shipped shall average not less than 17 feet 6 inches for the entire order. Not more than 5 per cent of the entire order may consist of two pieces coupled together.

12. **Threading and reaming.**—All pipe shall have a good Briggs' standard thread which will make a tight joint when tested by hydrostatic pressure at the mill. The thread shall not vary more than $1\frac{1}{2}$ turns either way when tested with a standardized ring or coupling. All burrs at the ends of the pipe shall be removed.

Solid tapped rings or split couplings shall be provided as thread protectors on all sizes 4 inches in diameter or larger. Protection shall be provided for smaller sizes when specified on the order.

13. **Couplings.**—The material shall be sound and free from injurious defects. Threads shall be clean-cut, of such pitch diameter as will make a tight joint and tapered to fit the Briggs' standard thread on the pipe. The ends shall be recessed.

14. **Marking.**—The length, the test pressure in pounds, and "Line" shall be stenciled on each length of pipe, and on sizes 6 inches and larger, except dipped or coated pipe, the weight of each length shall be stenciled.

15. **Finish.**—The finished pipe shall be reasonably straight and free from injurious defects.

16. **Inspection.**—(*a*) The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the pipe ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the pipe is being furnished in accordance with these specifications. (*b*) All tests and inspections shall be made at the place of manufacture and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Standard Specifications for Open-hearth "National" Line Pipe [1]

The specifications for open-hearth "National" line pipe are identical with those for Bessemer National line pipe, with the exception that in chemical composition the carbon shall not be over 0.15, phosphorus shall not be over 0.10, and sulphur shall not be over 0.06. The tensile strength shall be 50,000 pounds per square inch, the yield point 30,000 pounds per square inch, and the elongation 20 per cent in 8 inches.

(*b*) All tests and inspections shall be made at the place of manufacture and shall be so conducted as not to interfere unnecessarily with the operation of the works.

AMERICAN SOCIETY FOR TESTING MATERIALS SPECIFICATION FOR WELDED AND SEAMLESS STEEL PIPE

SERIAL DESIGNATION: A 53–21

Issued, 1920; Revised, 1921

1. **Material covered.**—These specifications cover "standard" and "extra strong" welded and seamless steel pipe, but not "double extra strong" pipe. Pipe ordered under these specifications are intended for bending, flanging and other special purposes.

I. MANUFACTURE

2. **Process.**—(*a*) The steel for welded pipe shall be of soft weldable quality made by the Bessemer or open-hearth process. The steel for seamless pipe shall be made by the open-hearth process.

(*b*) Welded pipe 3 inches or under in nominal diameter may be butt-welded, unless otherwise specified. Welded pipe over 3 inches in nominal diameter shall be lap-welded.

II. CHEMICAL PROPERTIES AND TESTS

3. **Chemical composition.**—Open-hearth steel shall conform to the following requirement as to chemical composition:

Phosphorus........................ not over 0.05 per cent

III. PHYSICAL PROPERTIES AND TESTS

4. **Tension tests.**—(*a*) The material shall conform to the following minimum requirements as to tensile properties:

	WELDED		SEAMLESS
	Bessemer	Open-hearth	Open-hearth
Tensile strength, pounds per square inch...	50,000	45,000	48,000
Yield point, pounds per square inch........	30,000	25,000	26,500
Elongation in 8 inches, per cent...........	18	20	18

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

5. **Hydrostatic tests.**—(*a*) Welded pipe shall be tested at the mill to the hydrostatic pressures specified in Table 1.

[1] National Tube Company open-hearth line specification No. 2-A, April 1, 1919, superseding specification No. 2, October 1, 1912.

TABLE 1

Hydrostatic Pressures for Welded Steel Pipe

(Pressures expressed in pounds per square inch)

(Black and galvanized)

Size (Nominal inside diameter), inches	"STANDARD" PIPE			"EXTRA STRONG" PIPE		
	Weight of pipe per linear foot, threaded and with couplings, pounds	Butt-weld	Lap-weld	Weight of pipe per linear foot, plain ends, pounds	Butt-weld	Lap-weld
1/8	....	700	....	....	700	
1/4	....	700	....	....	700	
3/8	....	700	....	....	700	
1/2	....	700	....	....	700	
3/4	....	700	....	....	700	
1	....	700	....	....	700	
1 1/4	....	700	1000	....	1500	2500
1 1/2	....	700	1000	....	1500	2500
2	....	700	1000	....	1500	2500
2 1/2	....	800	1000	....	1500	2000
3	....	800	1000	....	1500	2000
3 1/2	....	....	1000	....	....	2000
4	....	....	1000	....	....	2000
4 1/2	....	....	1000	....	....	1800
5	....	....	1000	......	....	1800
6	....	....	1000	....	....	1800
7	....	....	1000	....	....	1500
8	25.00	....	800			
8	28.81	....	1000	43.39	....	1500
9	34.19	....	900	48.73	....	1200
10	32.00	....	600			
10	35.00	....	700			
10	41.13	....	900	54.74	....	1000
11	46.25	....	800	60.08	....	1000
12	45.00	....	600			
12	50.71	....	800	65.42	....	1000

For pipes over 12 inches in inside diameter, the test pressures should be calculated by the formula, $P = \frac{2St}{D}$, in which P = pressure in pounds per square inch; S = fiber stress = 12,000 pounds per square inch; t = thickness of wall in inches; D = inside diameter in inches.

(*b*) Seamless pipe shall be tested at the mill to hydrostatic pressures not exceeding that required by the formula:

$$P=\frac{2St}{D},$$

in which P = pressure in pounds per square inch;
S = allowable fiber stress = 16,000 pounds per square inch;
t = thickness of wall in inches;
D = inside diameter in inches.

6. **Flattening tests.**—(*a*) For lap-welded pipe over 2 inches in diameter, a section of pipe 6 inches long shall be flattened between parallel plates until the distance between the plates is one-third the outside diameter of the pipe with the weld located 45° from the line of direction of the applied force, without developing cracks.

(*b*) For butt-welded pipe over 2 inches in diameter, a section of pipe 6 inches long shall be flattened between parallel plates until the distance between the plates is 60 per cent of the outside diameter of the pipe with the weld located 45° from the line of direction of the applied force, without developing cracks.

7. **Bend tests.**—For pipe 2 inches or under in diameter, a sufficient length of pipe shall withstand being bent cold through 90° around a cylindrical mandrel, the diameter of which is 12 times the nominal diameter of the pipe, without developing cracks at any portion and without opening the weld.

8. **Test specimens.**—(*a*) Test specimens shall consist of sections cut from a pipe. They shall be smooth on the ends and free from burrs.

(*b*) Tension test specimens shall be longitudinal.

(*c*) All specimens shall be tested cold.

9. **Number of tests.**—One of each of the tests specified in Sections 4, 6 and 7 may be made on a length in each lot of 500 or less, of each size. Each length shall be subjected to the hydrostatic test.

10. **Retests.**—If the results of the physical tests of any lot do not conform to the requirements specified in Sections 4, 6 and 7, retests of two additional pipes shall be made, each of which shall conform to the requirements specified.

IV. Standard Weights

11. **Standard weights.**—(*a*) The standard weights for pipe of various inside diameters are given in Table 2.

(*b*) Nipples shall be cut from pipe of the same weight and quality as described in these specifications.

12. **Permissible variations.**—The weight of the pipe shall not vary more than 5 per cent from that specified in Table 2.

13. **Lengths.**—Unless otherwise specified, pipe shall be furnished as to lengths in accordance with the following regular practice:

(*a*) Standard pipe shall be in random lengths of 16 to 22 feet, but not more than 5 per cent of the total number of lengths may be "jointers," which are two pieces coupled together. When ordered with plain ends, 5 per cent may be in lengths of 12 to 16 feet.

(*b*) Extra strong pipe shall be in random lengths of 12 to 22 feet. Five per cent may be in lengths of 6 to 12 feet.

V. Workmanship and Finish

14. **Workmanship.**—For pipe $1\frac{1}{2}$ inches or under in inside diameter, the outside diameter at any point shall not vary more than $\frac{1}{64}$ inch over nor more than $\frac{1}{32}$ inch under the standard size. For pipe 2 inches or over in inside diameter, the outside diameter shall not vary more than 1 per cent over or under the standard size.

TABLE 2

Standard Weights and Dimensions of Welded and Seamless Steel Pipe

(Black and galvanized)

Size (Nominal inside diameter), inches	"STANDARD" PIPE				"EXTRA STRONG" PIPE	
	Outside diameter, inches	Number of threads per inch	Thickness, inch	Weight of pipe per linear foot, threaded and with couplings, pounds	Thickness, inch	Weight of pipe per linear foot, plain ends, pounds
$\frac{1}{8}$	0.405	27	0.068	0.25	0.095	0.31
$\frac{1}{4}$	0.540	18	0.088	0.43	0.119	0.54
$\frac{3}{8}$	0.675	18	0.091	0.57	0.126	0.74
$\frac{1}{2}$	0.840	14	0.109	0.85	0.147	1.09
$\frac{3}{4}$	1.050	14	0.113	1.13	0.154	1.47
1	1.315	$11\frac{1}{2}$	0.133	1.68	0.179	2.17
$1\frac{1}{4}$	1.660	$11\frac{1}{2}$	0.140	2.28	0.191	3.00
$1\frac{1}{2}$	1.900	$11\frac{1}{2}$	0.145	2.73	0.200	3.63
2	2.375	$11\frac{1}{2}$	0.154	3.68	0.218	5.02
$2\frac{1}{2}$	2.875	8	0.203	5.82	0.276	7.66
3	3.500	8	0.216	7.62	0.300	10.25
$3\frac{1}{2}$	4.000	8	0.226	9.20	0.318	12.51
4	4.500	8	0.237	10.89	0.337	14.98
$4\frac{1}{2}$	5.000	8	0.247	12.64	0.355	17.61
5	5.563	8	0.258	14.81	0.375	20.78
6	6.625	8	0.280	19.19	0.432	28.57
7	7.625	8	0.301	23.77	0.500	38.05
*8	8.625	8	0.277	25.00		
8	8.625	8	0.322	28.81	0.500	43.39
9	9.625	8	0.342	34.19	0.500	48.73
*10	10.750	8	0.279	32.00		
*10	10.750	8	0.307	35.00		
10	10.750	8	0.365	41.13	0.500	54.74
11	11.750	8	0.375	46.25	0.500	60.08
*12	12.750	8	0.330	45.00		
12	12.750	8	0.375	50.71	0.500	65.42

* Unless specifically stated on the order the lighter weights will not be furnished. Weights given in the table are for pipes up to and including 12 inches in nominal inside diameter, with threaded ends and couplings; sizes larger than those shown in the table are measured by the outside diameter and will be furnished with plain ends unless otherwise specified; for such sizes it will be necessary to accept Manufacturer's weights or calculate the weights on the basis of 1 cubic inch of steel weighing 0.2833 pound.

15. **Ends.**—Unless otherwise specified, pipe shall conform to the following regular practice:

(*a*) Each end of standard welded pipe shall be threaded.

(*b*) Extra strong welded pipe and standard and extra strong seamless pipe shall be furnished with plain ends.

Threads.—(*c*) All threads shall be in accordance with the American Standard [1] and cut so as to make a tight joint when the pipe is tested at the mill to the specified internal hydrostatic pressure. The variation from the standard, when tested with the standard working gage, shall not exceed a maximum of one and one-half turns either way.

Couplings.—(*d*) Each length of threaded pipe shall be provided with one coupling, having clean-cut threads of such a pitch diameter as to make a tight joint. Couplings may be made of wrought iron or steel.

16. **Finish.**—The finished pipe shall be reasonably straight and free from injurious defects. All burrs at the ends of the pipe shall be removed.

VI. Inspection and Rejection

17. **Inspection.**—The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the pipe ordered. The manufacturer shall afford the inspector, free of charge, all reasonable facilities to satisfy him that the pipes are being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

18. **Rejection.**—Each length of pipe which develops injurious defects in shop working or application will be rejected, and the manufacturer shall be notified.

Pipe and Special Joints Used in the Oil Country

The illustrations, Figs. 3 to 10 inclusive, show some of the pipe joints that are widely used in the industries related to drilling.

Care in handling joints.—To get the best results in drilling, to save time and increase the life of the casing, considerable care should be taken in handling the joints.

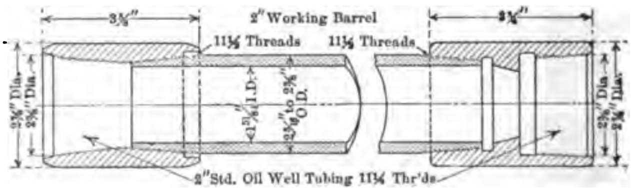

Fig. 43.—2-inch working barrel.

Lubrication of joints.—Joints will screw on and off much more readily if the threads on both pipe and coupling have been previously cleaned of sand and grit and treated with a good application of heavy oil or grease which has been mixed with graphite.

Working barrels.—The working barrels, sizes and weights of which are given in table shown below are manufactured from specially made lap-welded pipe. The steel from which these lap-welded pipes are made is of a special composition with a view to obtaining a hard, smooth surface in the finished working barrel.

[1] A complete description of the American Standard Pipe Thread is contained in the Pipe Thread Standard prepared under the sponsorship of the American Gas Association and the American Society of Mechanical Engineers and approved as American Standard by the American Engineering Standards Committee.

Table of Lengths and Weights of Working Barrels

Lengths of borking warrels	2-inch Barrel			2½ inch Barrel			3-inch Barrel			4-inch Barrel		
	Nominal weights of working barrels, complete with both couplings	Weight of upper coupling	Weight of lower coupling	Nominal weights of working barrels, complete with both couplings	Weight of upper coupling	Weight of lower coupling	Nominal weights of working barrels, complete with both couplings	Weight of upper coupling	Weight of lower coupling	Nominal weights of working barrels, complete with both couplings	Weight of upper coupling	Weight of lower coupling
Ft. In.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
4–0	29	2.5	3.5	31	3.5	5	44	5.5	6.5	66	8	9
4–6	34	....	....	35	....	....	48	....	....	72	....	....
5–0	37	....	....	38	....	....	53	....	....	78	....	....
5–6	40	....	....	41	....	....	57	....	....	84	....	....
6–0	43	....	....	45	....	....	61	....	....	90	....	....
6–6	46	....	....	47	....	....	65	....	....	96	....	....
7–0	49	....	....	50	....	....	69	....	....	103	....	....
7–6	53	....	....	54	....	....	74	....	....	109	....	....
8–0	56	....	....	57	....	....	77	....	....	115	....	....
9–0	63	....	....	64	....	....	85	....	....	127	....	....
10–0	70	....	....	71	....	....	93	....	....	139	....	....

2 and 2½-inch working barrels are threaded 11½ threads per inch. 3- and 4-inch working barrels are threaded 14 threads per inch.

Relative Discharging Capacities of Pipe for Water

Actual Internal Diameter	0.269	0.364	0.493	0.622	0.824	1.049	1.380	1.610	2.067	2.469	3.068	3.548	4.026	4.506	5.047	6.065
Nominal Internal Diameter	**1/8**	**1/4**	**3/8**	**1/2**	**3/4**	**1**	**1 1/4**	**1 1/2**	**2**	**2 1/2**	**3**	**3 1/2**	**4**	**4 1/2**	**5**	**6**
1/8	1															
1/4	2.1	1														
3/8	4.5	2.1	1													
1/2	8	3.8	1.8	1												
3/4	16	8	3.6	2	1											
1	30	14	6.6	3.7	1.8	1										
1 1/4	60	28	13	7	3.6	2	1									
1 1/2	83	41	19	11	5.3	2.9	1.5	1								
2	161	77	36	20	10	5.5	2.7	1.9	1							
2 1/2	255	120	56	31	16	8	4.3	2.9	1.6	1						
3	439	206	97	54	27	15	7	5	2.7	1.7	1					
3 1/2	632	297	139	78	38	21	11	7	3.9	2.5	1.4	1				
4	867	407	191	107	53	29	15	10	5.3	3.4	2	1.4	1			
4 1/2	1,148	539	253	141	70	38	19	13	7	4.5	2.6	1.8	1.3	1		
5	1,525	716	335	188	93	51	26	17	9	6	3.5	2.4	1.8	1.3	1	
6	2,414	1,133	531	297	147	80	40	28	15	9	5.5	3.8	2.8	2.1	1.6	1
7	3,133	1,635	756	428	212	116	58	40	21	14	8	5.5	4	3	2.3	1.4
8	4,795	2,251	1,054	590	292	160	80	55	29	19	10.9	7.6	5.5	4.2	3.1	2
9	6,360	2,990	1,401	783	388	212	107	73	39	25	14	10	7.3	5.5	4.2	2.6
10	8,468	3,976	1,862	1,042	516	282	142	97	52	33	19	13	10	7.4	5.6	3.5
11	10,693	5,020	2,352	1,315	651	356	179	122	65	42	24	17	12	9.3	7	4.4
12	13,292	7,210	2,923	1,635	809	443	223	152	81	52	30	21	15	12	8.7	5.5
13	17,028	6,994	3,745	2,094	1,037	567	286	194	104	67	39	27	20	15	11	7
14	20,425	9,589	4,492	2,512	1,244	680	343	233	125	80	46	32	24	18	13	8.5
15	24,199	11,361	5,322	2,976	1,474	806	406	276	148	95	55	38	28	21	16	10
18 O. D.	31,750	14,906	6,982	3,905	1,933	1,057	533	362	194	124	72	50	37	28	21	13
20 O. D.	41,928	19,685	9,221	5,157	2,553	1,396	703	478	256	164	95	66	48	37	27	17
22 O. D.	53,848	25,281	11,842	6,623	3,279	1,793	903	614	329	211	123	85	62	47	35	22
24 O. D.	67,599	31,737	14,866	8,315	4,116	2,251	1,134	771	413	265	154	107	78	59	44	28
26 O. D.	83,267	39,093	18,312	10,242	5,070	2,773	1,397	950	509	326	190	132	96	73	55	34
28 O. D.	100,932	47,387	22,197	12,415	6,146	3,361	1,693	1,152	617	395	230	160	116	88	66	42
30 O. D.	120,675	56,655	26,530	14,843	7,348	4,018	2,024	1,377	737	473	275	191	139	105	79	50

Calculations based on the inside diameters of standard pipe *

Formula

Relative discharge capacity = $\sqrt{\text{inside diameter}^5}$

* Book of Standards (National Tube Company), 1917 Edition, page 306.

Relative Discharging Capacities of Pipe for Water—Continued

Actual Internal Diameter	7.023	7.981	8.941	10.020	11.000	12.000	13.250	14.250	15.250	17.000	19.000	21.000	23.000	25.000	27.000	29.000
Nominal Internal Diameter	**7**	**8**	**9**	**10**	**11**	**12**	**14 O. D.**	**15 O. D.**	**16 O. D.**	**18 O. D.**	**20 O. D.**	**22 O. D.**	**24 O. D.**	**26 O. D.**	**28 O. D.**	**30 O. D.**
⅛																
¼																
⅜																
½																
¾																
1																
1¼																
1½																
2																
2½																
3																
3½																
4																
4½																
5																
6																
7	1															
8	1.3	1														
9	1.8	1.3	1													
10	2.4	1.8	1.3	1												
11	3	2.2	1.7	1.3	1											
12	3.8	2.8	2.1	1.6	1.2	1										
13	4.9	3.6	2.7	2	1.6	1.3	1									
14	5.9	4.3	3.2	2.4	1.9	1.5	1.2	1								
15	6.9	5	3.8	2.9	2.3	1.8	1.4	1.2	1							
18 O. D.	9.1	6.6	5	3.7	3	2.4	1.9	1.6	1.3	1						
20 O. D.	12	8.7	6.6	5	3.9	3.2	2.5	2.1	1.7	1.3	1					
22 O. D.	15	11	8.5	6.4	5	4.1	3.2	2.6	2.2	1.7	1.3	1				
24 O. D.	19	14	11	8	6.3	5.1	4	3.3	2.8	2.1	1.6	1.3	1			
26 O. D.	24	17	13	9.8	7.8	6.3	4.9	4.1	3.4	2.6	2	1.5	1.2	1		
28 O. D.	29	21	16	12	9.4	7.6	5.9	4.9	4.2	3.2	2.4	1.9	1.5	1.2	1	
30 O. D.	35	25	19	14	11	9.1	7.1	5.9	5	3.8	2.9	2.2	1.8	1.4	1.2	1

Calculations based on the inside diameters of standard pipe *

Formula

Relative discharge capacity = $\sqrt{\text{inside diameter}^5}$

* Book of Standards (National Tube Company), 1917 Edition, pages 306–309.

Working barrels are made from a special grade of lap-welded Bessemer steel pipe carrying about 0.5 per cent manganese. The pipe is given several cold-drawing oper-

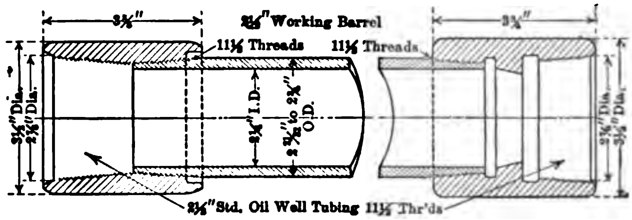

Fig. 44.—2½-inch working barrel.

ations, making the inside surface of the working barrel extremely smooth and bright, and which also renders the surface somewhat harder.

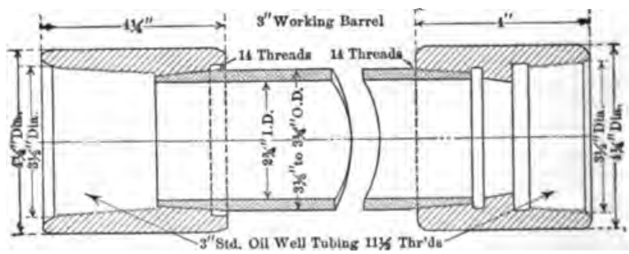

Fig. 45.—3-inch working barrel.

This process of manufacturing working barrels makes them especially adapted and suited for the hard service to which they are subjected in pumping.

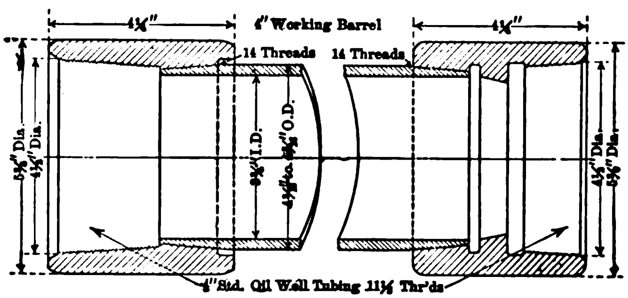

Fig. 46.—4-inch working barrel.

Corrosion and Protective Coatings

Corrosion of wrought iron and steel in general.—While there is a vast difference in the amount of corrosion of iron and steel under different conditions, and while it has been proved that the relative corrosion of these metals also varies decidedly with surrounding conditions, there are certain fundamental causes which underlie all cases

of corrosion and which should be understood by those interested in this problem in any of its phases.

Every metal when placed in water is subjected to a fixed tendency to go into solution. This is wholly a matter of electrochemical activity and varies to a definite extent with each metal. Thus the initial reaction in the process of corrosion is analogous to solution in acid, pure water being in effect a very weak acid. The acidity of the water depends on the concentration of the so-called hydrogen ions in water which determines the initial speed of attack. As in all electrochemical reactions, however, the initial speed of solution soon slows down as the numerous electrochemical couples which form over the surface of the metal become " polarized " due to the accumulation of hydrogen on their cathodic surfaces, ultimately stopping the solution of the metal. In the case of iron a small amount of the metal (less than 10 p.p.m.) is dissolved as ferrous hydrate, which also has a decided retarding action on the solution of the metal. This, the first stage of the corrosion of iron and steel, while essential, is not a serious matter if the reaction between water and iron can be stopped at this point. As a matter of fact this reaction cannot proceed unless in some way or other the hydrogen film protecting the metal is removed. This is usually brought about by means of something in the nature of a depolarizer, general free oxygen, which also combines with ferrous hydrate, forming insoluble ferric hydrate, commonly known as rust.

This, the second stage of corrosion, is thus caused by the oxidation of hydrogen and ferrous hydrate in solution by the free oxygen of the atmosphere. Oxygen is soluble in water at normal temperature to the extent of about ten parts by weight per million (7 c.c. per liter) and as water readily absorbs more oxygen when this element is used up, as in rusting under atmospheric conditions, it will be seen that under such conditions the reaction will continue until the metal has all been destroyed, or the reaction may be brought to a stop at any time through exhaustion of the available supply of oxygen. The latter case is illustrated in any closed water system, as in the case of any metallic water pipe where the amount of free oxygen will be found to drop as the water travels from the inlet so that if the pipe is long enough the corrosion will finally be reduced to a negligible amount.

The deterioration of water and oil lines is caused mainly by outside corrosion due to soil conditions, which resemble more nearly corrosion under water than atmospheric corrosion. Internal corrosion of oil lines from corrosive water intermixed with the oil is sometimes a serious condition which so far has not been remedied. Underground corrosion may be accelerated by the presence of certain salts or acids in the soil, and by the more ready access of free oxygen either by direct circulation of air or by means of underground waters which have become charged with oxygen and carbonic acid. The corrosive action is greatly increased by a rise in temperature and velocity of water within certain limits and by contact of the metal with any materials which tend to intensify galvanic action, such as *cinder or certain kinds of mixed trench fill*, or even the heavy mill scale formed in hot finishing of the pipe, which has a strong tendency where firmly attached to localize corrosion and thus cause pitting. Rust once formed on the surface also has this effect to a somewhat lesser extent.

From this brief outline of the main factors which tend to control corrosion it will be seen how important it is to keep all parts of the pipe from contact with wet soil or water, through the use of protective coatings of substantial thickness, properly applied.

The influence of the composition of the metal under most conditions does not seem to have much effect in itself, all other things being equal. Where wrought iron, Bessemer steel and basic open-hearth steel have been in service thirty years or more, the records

NOTE.—Those who want to go into further details of the mechanism of corrosion may consult "Preservation of Hot Water Pipe," Speller and Knowland, Trans. Am. Soc. of H. & V. Engs., Vol. 24, 1918, p. 217.

of such lines show failures in some places and practically no corrosion in other places, depending on soil conditions, drainage and other factors. It is very difficult to make a strict comparison of two or more materials in a pipe-line underground, for the reason that the conditions are so variable; but it is significant that wrought-iron forged couplings have up to the present always been used on steel pipe and so far as can be learned from many cases examined no difference in the depth of the corrosion has been found although wrought-iron couplings are hammer forged and consequently should have a better structure and be more resistant than the pipe. So far as the metal itself is concerned, the factor of prime importance as affecting initial corrosion seems to be the surface finish, particularly the mill scale which is decidedly electronegative to iron and therefore is a more or less powerful accelerator of corrosion.

Protection against exterior corrosion.—From the above it will be understood that the main object of protective coatings is to exclude water from contact with the metal.

Such coatings as are available at present are by their very nature easily damaged and thus rendered practically useless if subject to abrasion after being applied. No coating has yet been found which has any chance of protecting such a material as oil-well casing. Most of what follows is therefore, applicable mainly to line pipe or water pipe subjected to underground corrosion.

Before any coating is applied in the field all loose rust or scale should be removed and a thin priming coat applied to the clean dry surface after the line is put together and ready to be ditched. Where a priming coat is applied at the place of manufacture, which is preferable, the surface should be cleaned and freshened up before any further protective coating is applied in the field. The subsequent protection needed depends on conditions which should be determined by a careful survey of the nature of the soil and drainage of the territory in which the line is to be laid. Old oil lines which were originally laid without any more protection than a simple coat of paint, as a rule have not given serious trouble for more than 10 per cent of their length. Therefore in the interest of economy it is obvious that the places which are likely to cause trouble should be located and a type of protection selected for each locality. In well-drained sand or clay soils a second coat of some reputable pipe compound may be all that is necessary or perhaps one coat may be sufficient, but in wet marshy places, especially where the ground water is corrosive, a much more substantial waterproofing will be necessary. Wherever the ditch can be drained economically it will of course be of considerable advantage to do so.

The function of the priming coat is principally to afford a strong bond between the thicker protective coating and the metal, and is essential where the subsequent coat is applied hot to the cold metal. The priming coat may consist of coal tar or a pure asphalt dissolved in naphtha or benzol to a thin consistency. It is of little protective value in itself as is true of paints in general, when underground. To be of any practical value where underground corrosion is known to occur, a non-porous coating of substantial thickness is required.

Protective coatings.—The coatings which have given the best service may be classified as:

1. Melted bituminous mixtures which can be safely heated to 350–400° F. with a melting point of about 150° F. may be applied in the field with suitable brushes operated by hand or mechanically. Sometimes a coating of this class is poured over the pipe, the surplus being caught in a strip of canvas about 30 inches wide held by two men, by which means the coating can be worked evenly over the under side of the pipe. In this way, with care and practice, a coating from $\frac{1}{16}$ to $\frac{1}{4}$ inch thick may be applied without much variation in thickness.

The well-known dips applied at the works by manufacturers come under this heading. Conditions are more favorable for the application of these coatings at the mill,

but the manufacturer has to take into consideration the problem of transporting the pipe without injury and is limited as to the coating material by this consideration. Most pipe has to stand a wide range of temperature fluctuation en route to destination, often as much as 100° F. If the temperature drops below the brittle point the coating is liable to crack off and if the solar heat absorbed raises the temperature of the coating above the melting point the mixture runs. In addition there is always a certain amount of damage due to abrasion in handling, all of which necessitates careful inspection and attention to repairs. Coal-tar pitch when properly refined makes one of the best preservative dips, but unfortunately the range between the brittle and melting points of this material rarely exceeds 45° F. so that an asphalt blend must be used in most cases where the pipe has to be shipped any distance after coating. Some of the asphalt mixtures which have been developed for this purpose have a temperature range (brittle point to melting point) of 120° F. or 130° F. and have proved quite satisfactory in service. The absorption of solar heat may be limited considerably by dusting the surface of the pipe with Portland cement or fine white sand. A coating of whitewash applied over the sanded surface has been tried and was found to keep the temperature of the coating down to atmospheric temperature under the summer sun.

Fig. 47—Wrapping dipped pipe with saturated fabric.

2. Under some conditions the coating above described may be reinforced with advantage by a strip of fabric 6 or 8 inches wide wound spirally around the pipe while the coating is hot. This is easily done at the mill after the pipe has received the dip coat by means of a machine designed for the purpose (Fig. 47). The fabric should be dried in vacuum and saturated by passing through a small tank of the asphaltic mixture as it passes on to the pipe. Naturally it is possible to make a better job with this type of coating in the mills while the pipe is clean and dry. A saturated fabric in rolls of suitable size would be convenient for this purpose in the field, such as a large-size electric tape or the fabric may be saturated after application by a final coat of thin consistency. This method of protection has been used for some years, having been found to give good service, and has become standard with one American manufacturers for bell-and-spigot steel water pipe.

3. Where the ditch is wet most of the time, especially where stray electric currents are likely to occur in the vicinity of the pipe, provision should be made to keep these stray currents off this section of the pipe by the use of insulated joints.[1] The pipe should then be boxed in as indicated in Fig. 48 after being cleaned and receiving the usual priming coat. The pipe is supported underneath every 10 feet or so on some non-porous insulating material such as a piece of hard-burned sewer pipe or heavy glass about $\frac{3}{4}$ inch thick. An asphaltic compound such as parolite or some similar mixture with a melting point of about 150° F. which has been heated so as to run readily, is poured in between the pipe and the box on one side. Particular care should be taken that the asphalt passes underneath the pipe without leaving air pockets

[1] See the report of American Committee on electrolysis, published by A. I. E. E., 33 West 39th Street, N. Y.

which would of course leave an opening for water to penetrate the coating. This coating has been found to be very effective both against corrosion and electrolysis when applied uniformly and not less than ¾ inch thick. When the sides of the trench are stable, the side boards may be removed and the fill tamped in around the coating; however, it is better as a rule to leave the box undisturbed.

4. Where corrosive conditions are severe as in marshy places where the water is brackish or acid, a covering of concrete has proved to give the best protection. A mix of 3 of sand to 1 Portland cement thoroughly worked together should be poured between the pipe and the box as in the case of the bituminous coating (see Fig. 48). The pipe should be centered in the box and supported on non-porous material at suitable intervals so that the coating will not be less than 2 inches in thickness for 8 or 12-inch line pipe. No priming coat is required but the surface of the pipe should be well cleaned to remove all loose scale and dirt. The concrete should be moist enough to flow readily and should finally be formed up over the top of the pipe to the required thickness. The same precautions should be taken as under (3) to avoid air pockets, with careful inspection to avoid leaving any uncoated places.

Thorough mixing of the sand and cement insures a waterproof concrete and is better than depending on some waterproofing compound introduced into the mixture.

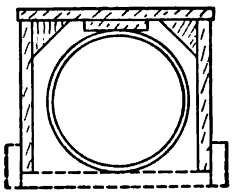

Fig. 48.—Method of boxing pipe for concreting.

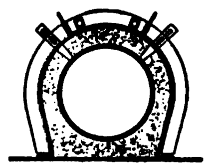

Fig. 49.—Portable steel frame for applying concrete coating.

The side boards may be removed and used again. If this is done a coating of asphalt may be applied to the sides of the concrete before filling in the ditch. A coat of hot asphalt should be applied to the bottom and sides of the box before the pipe is put into place.

Oil lines protected in this way in brackish water have been protected from corrosion for twenty-five years near the New Jersey coast, but concrete coatings are not proof against electrolysis and are liable to disintegration in wet alkali soils. Precautions must be taken to guard against, or repair, cracking from expansion or contraction, or settlement.

Forms made of thin corrguated-steel sheets have been tried and could probably be developed into a convenient and economical device where lumber is scarce. Another design for a portable steel form for use in the application of a layer of concrete to the outside of the pipe in the field is shown in Fig. 49.

The above includes what is believed to be the best type of coating of each class, although each situation will present problems of its own requiring judgment in the selection of the best treatment.

GENERAL TABLES

The following tables have been selected as embodying engineering data not previously included in the text, and which require only occasional reference. Lack of space precludes any attempt at completeness or finality. The reader is referred to the standard engineering pocketbooks of Kent, Marks, and Trautwine for additional facts and information.

WEIGHTS AND MEASURES

Where possible these tables have been taken from the publications of the U. S. Bureau of Standards.

Measures of Length—Long Measure

12 inches	= 1 foot
3 feet	= 1 yard
1760 yards, or 5280 feet	= 1 mile

Additional Measures of Length in Occasional Use

1000 mils	= 1 inch
4 inches	= 1 hand
9 inches	= 1 span
$2\frac{1}{2}$ feet	= 1 military pace
2 yards	= 1 fathom
$5\frac{1}{2}$ yards, or $16\frac{1}{2}$ feet	= 1 rod (formerly also called pole or perch)

Old Land Measure

7.92 inches	= 1 link
100 links, or 66 feet, or 4 rods	= 1 chain
10 chains, or 220 yards	= 1 furlong
8 furlongs, or 80 chains	= 1 mile
10 square chains	= 1 acre

Nautical Measure

6080.26 feet, or 1.15156 statute miles	= 1 nautical mile, or knot [1]
3 nautical miles	= 1 league
60 nautical miles, or 69.168 statute miles	= 1 degree (at the equator)
360 degrees	= circumference of the earth at the equator.

[1] The British Admiralty takes the round figure of 6080 feet, which is the length of the "measured mile" used in trials of vessels. The value varies from 6080.26 to 6088.44 feet according to different measures of the earth's diameter. There is a difference of opinion among writers as to the use of the word "knot" to mean length or a distance—some holding that it should be used to denote a rate of speed. The length between knots on the log line is $\frac{1}{120}$ of a nautical mile, or 50.7 feet, when a half-minute glass is used; so that a speed of 10 knots is equal to 10 nautical miles per hour.

FOREIGN UNITS OF WEIGHTS AND MEASURES USED IN THE OIL INDUSTRY

ARGENTINA.—Metric system.

AUSTRIA.

1 metric centner or quintal = 100 kilograms
= 220.462 pounds, avdp.
= 0.71905 U.S. barrel of 42 gallons, crude petroleum

BOLIVIA.—Metric system.

BRAZIL.

1 libra = 1.012 pounds, avdp.
1 arroba = 32.38 pounds, avdp.
1 quintal = 129.54 pounds, avdp.

BURMA.

1 viss = 100 tikals = 3.5 pounds, avdp.
1 Indian or Imperial maund = 82.28 pounds, avdp.
1 maund = 40 seers = 9.8098 Imperial gallons

CANADA.

1 barrel = 35 Imperial gallons = 1 U. S. barrel of 42 gallons (approximately)

DUTCH EAST INDIES.—Metric system.

1 gallon Borneo crude = 7.5322 pounds
1 gallon Java crude = 7.1924 pounds
1 gallon Sumatra crude = 6.7754 pounds

(Above figures are those standardized for computation of production by U. S. Geological Survey.)

EGYPT.—Metric system.

1 metric ton, crude petroleum = 7.5 U. S. barrels

FRANCE.—Metric system.

GERMANY.—Metric system.

GREAT BRITAIN.

1 Imperial gallon = 1.2003 U. S. gallons

HOLLAND.—Metric system.

ITALY.—Metric system.

1 metric ton, crude petroleum = 7.1095 U. S. barrels

JAPAN.

10 go = 1 shoō = 1.5872 Imperial quarts = 0.4746 U. S. gallon
10 shoō = 1 to = 3.9681 Imperial gallons = 4.746 U. S. gallons
10 to = 1 koku = 39.6814 Imperial gallons = 1.136 U. S. barrels

MEXICO.—Metric and U. S. standard. = 47.46 U. S. gallons—N. B.

PERU.—Metric system.

1 metric ton, crude petroleum = 7.5 U. S. barrels.

RUMANIA.—Metric system.

1 metric ton, crude petroleum = 7.19 U. S. barrels.

RUSSIA.

1 pood = 36.112 pounds, avdp.
1 metric ton, crude petroleum = 61.05 poods
1 U. S. barrel = 8.33 poods, crude petroleum
= 8.00 poods, illuminating oil
= 8.18 poods, lubricating oil
= 9.00 poods residuum
= 7.5 poods naphtha
= 8.3775 poods other products

VENEZUELA.—Metric system.

TABLES OF INTERRELATION

1. Units of

Units	Inches	Links	Feet	Yards	Rods
1 inch =	1	0.126 263	0.083 333 3	0.027 777 8	0 005 050 51
1 link =	7.92	1	0.66	0.22	0 04
1 foot =	12	1.515 152	1	0.333 333	0.060 606 1
1 yard =	36	4.545 45	3	1	0.181 818
1 rod =	198	25	16.5	5.5	1
1 chain =	792	100	66	22	4
1 mile =	63,360	8000	5280	1760	320
1 centimeter =	0.3937	0.049 709 60	0.032 808 33	0.010 936 111	0.001 988 384
1 meter =	39.37	4.970 960	3.280 833	1.093 611 1	0.198 838 4

2. Units of

Units	Square inches	Square links	Square feet	Square yards	Square rods	Square chains
1 square inch =	1	0.015 942 3	0 006 944 44	0.000 771 605	0.000 025 507 6	0.000 001 594 23
1 square link =	62.7264	1	0.435 6	0.048 4	0.001 6	0.000 1
1 square foot =	144	2.295 684	1	0.111 111 1	0.003 673 09	0.000 229 568
1 square yard =	1,296	20.661 2	9	1	0.033 057 85	0.002 066 12
1 square rod =	39,204	625	272.25	30.25	1	0.062 5
1 square chain =	627,264	10,000	4,356	484	16	1
1 acre =	6,272,640	100,000	43,560	4,840	160	10
1 square mile =	4,014,489,600	64,000,000	27,878,400	3,097,600	102 400	6400
1 square centimeter =	0.154 999 7	0.002 471 04	0.001 076 387	0.000 119 598 5	0.000 003 953 67	0.000 000 247 104
1 square meter =	1549.996 9	24.710 4	10.763 87	1.195 985	0 039 536 7	0.002 471 04
1 hectare =	15,499,969	247,104	107,638.7	11,959.85	395.367	24.710 4

3. Units of

Units	Cubic inches	Cubic feet	Cubic yards
1 cubic inch =	1	0.000 578 704	0.000 021 433 47
1 cubic foot =	1,728	1	0.037 037 0
1 cubic yard =	46,656	27	1
1 cubic centimeter =	0.061 023 38	0.000 035 314 45	0.000 001 307 94
1 cubic decimeter =	61.023 38	0.035 314 45	0.001 307 943
1 cubic meter =	61,023.38	35.314 45	1.307 942 8

4. Units of Capacity—

Units	Minims	Fluid drams	Fluid ounces	Gills	Liquid pints
1 minim =	1	0.016 666 7	0.002 083 33	0.000 520 833	0.000 130 208
1 fluid dram =	60	1	0.125	0.031 25	0.007 812 5
1 fluid ounce =	480	8	1	0.25	0.062 5
1 gill =	1,920	32	4	1	0.25
1 liquid pint =	7,680	128	16	4	1
1 liquid quart =	15,360	256	32	8	2
1 gallon =	61,440	1,024	128	32	8
1 milliliter =	16.231 1	0.270 518	0.033 814 7	0.008 453 68	0.002 113 42
1 liter =	16,231.1	270.518	33.814 7	8.453 68	2.113 42
1 cubic inch =	265.974	4.432 90	0.554 113	0.138 528	0.034 632 0

OF UNITS OF MEASUREMENT

Length

Chains	Miles	Centimeters	Meters	Units
0.001 262 63	0.000 015 782 8	2.540 005	0.025 400 05	=1 inch
0.01	0.000 125	20.116 84	0.201 168 4	=1 link
0.015 151 5	0.000 189 393 9	30.480 06	0.304 800 6	=1 foot
0.045 454 5	0.000 568 182	91.440 18	0.914 401 8	=1 yard
0.25	0.003 125	502.921 0	5.029 210	=1 rod
1	0.012 5	2,011.684	20.116 84	=1 chain
80	1	160,934.72	1,609.347 2	=1 mile
0.000 497 096 0	0.000 006 213 699	1	0.01	=1 centimeter
0.049 709 60	0.000 621 369 9	100	1	=1 meter

Area

Acres	Square miles	Square centimeters	Square meters	Hectares	Units
0.000 000 159 423	0.000 000 000 249 1	6.451 626	0.000 645 162 6	0.000 000 064 516	=1 square inch
0.000 01	0.000 000 015 625	404.687 3	0.040 468 73	0.000 004 046 87	=1 square link
0.000 022 956 8	0.000 000 035 870 1	929.034 1	0.092 903 41	0.000 009 290 34	=1 square foot
0.000 206 612	0.000 000 322 831	8,361.307	0.836 130 7	0.000 083 613 1	=1 square yard
0.006 25	0.000 009 765 625	252,929.5	25.292 95	0.002 529 295	=1 square rod
0.1	0.000 156 25	4 046 873	404.687 3	0.040 468 7	=1 square chain
1	0.001 562 5	4 046 872 6	4046.873	0.404 687	=1 acre
640	1	25,899,984,703	2,589,998	258.999 8	=1 square mile
0.000 000 024 710 4	0.000 000 000 038 610 06	1	0.000 1	0.000 000 01	=1 square centimeter
0.000 247 104	0.000 000 386 100 6	10,000	1	0.000 1	=1 square meter
2.471 04	0.003 861 006	100,000,000	10,000	1	=1 hectare

Volume

Cubic centimeters	Cubic decimeters	Cubic meters	Units
16.387 162	0.016 387 16	0.000 016 387 16	=1 cubic inch
28,317.016	28.317 016	0.028 317 016	=1 cubic foot
764,559.4	764.559 4	0.764 559 4	=1 cubic yard
1	0.001	0.000 001	=1 cubic centimeter
1,000	1	0.001	=1 cubic decimeter
1,000,000	1000	1	=1 cubic meter

Liquid Measure

Liquid quarts	Gallons	Milliliters	Liters	Cubic inches	Units
0.000 065 104	0.000 016 276	0.061 610 2	0.000 061 610 2	0.003 759 77	=1 minim
0.003 906 25	0.000 976 562	3.696 61	0.003 696 61	0.225 586	=1 fluid dram
0.031 25	0.007 812 5	29.572 9	0.029 572 9	1.804 69	=1 fluid ounce
0.125	0.031 25	118.292	0.118 292	7.218 75	=1 gill
0.5	0.125	473.167	0.473 167	28.875	=1 liquid pint
1	0.25	946.333	0.946 333	57.75	=1 liquid quart
4	1	3785.332	3.785 332	231	=1 gallon
0.001 056 71	0.000 264 178	1	0.001	0.061 025 0	=1 milliliter
1.056 71	0.264 178	1000	1	61.025 0	=1 liter
0.017 316 0	0.004 329 00	16.386 7	0.016 386 7	1	=1 cubic inch

TABLES OF INTERRELATION

5. UNITS OF CAPACITY—

Units	Dry pints	Dry quarts	Pecks	Bushels
1 dry pint =	1	0.5	0.062 5	0.015 625
1 dry quart =	2	1	0.125	0.031 25
1 peck =	16	8	1	0.25
1 bushel =	64	32	4	1
1 liter =	1.816 20	0.908 102	0.113 513	0.028 378
1 dekaliter =	18.162 0	9.081 02	1.135 13	0.283 78
1 cubic inch =	0.029 761 6	0.014 880 8	0.001 860 10	0.000 465 025

6. UNITS OF MASS LESS

Units	Grains	Apothecaries' scruples	Pennyweights	Avoirdupois drams	Apothecaries' drams	Avoirdupois ounces
1 grain =	1	0.05	0.041 666 67	0.036 571 43	0.016 666 7	0.002 285 71
1 apoth. scruple =	20	1	0.833 333 3	0.731 428 6	0.333 333	0.045 714 3
1 pennyweight =	24	1.2	1	0.877 714 3	0.4	0.054 857 1
1 avdp. dram =	27.343 75	1.367 187 5	1.139 323	1	0.455 729 2	0.062 5
1 apoth. dram =	60	3	2.5	2.194 286	1	0.187 142 9
1 avdp. ounce =	437.5	21.875	18.229 17	16	7.291 66	1
1 apoth. or troy ounce =	480	24	20	17.554 28	8	1.097 142 9
1 apoth. or troy pound =	5,760	288	240	210.651 4	96	13.165 714
1 avdp. pound =	7,000	350	291.666 7	256	116.666 7	16
1 milligram =	0.015 432 356	0.000 771 618	0.000 643 014 8	0.000 564 383 3	0.000 257 205 9	0.000 035 273 96
1 gram =	15.432 356	0.771 618	0.643 014 85	0.564 383 3	0.257 205 9	0.035 273 96
1 kilogram =	15,432.356	771.617 8	643.014 85	564.383 32	257.205 94	35.273 96

7. UNITS OF MASS GREATER

Units	Avoirdupois ounces	Avoirdupois pounds	Short hundred weights	Short tons
1 avoirdupois ounce =	1	0.062 5	0.000 625	0.000 031 25
1 avoirdupois pound =	16	1	0.01	0.000 5
1 short hundredweight =	1,600	100	1	0.05
1 short ton =	32,000	2000	20	1
1 long ton =	35,840	2240	22.4	1.12
1 kilogram =	35.273 957	2.204 622 34	0.022 046 223	0.001 102 311 2
1 metric ton =	35,273.957	2204.622 34	22.046 223	1.102 311 2

OF UNITS OF MEASUREMENT—*Continued*

Dry Measure

Liters	Dekaliters	Cubic inches	Units
0.550 599	0.055 060	33.600 312 5	=1 dry pint
1.101 198	0.110 120	67.200 625	=1 dry quart
8.809 58	0.880 958	537.605	=1 peck
35.238 3	3.523 83	2150.42	=1 bushel
1	0.1	61.025 0	=1 liter
10	1	610.250	=1 dekaliter
0.016 386 7	0.001 638 67	1	=1 cubic inch

than Pounds and Kilograms

Apothecaries' or troy ounces	Apothecaries' or troy pounds	Avoirdupois pounds	Milligrams	Grams	Kilograms	Units
0.002 083 33	0.000 173 611 1	0.000 142 857 1	64.798 918	0.064 798 918	0.000 064 798 9	=1 grain
0.041 666 7	0.003 472 222	0.002 857 143	1,295.978 4	1.295 978 4	0.001 295 978	=1 apoth. scruple
0.05	0.004 166 667	0.003 428 571	1,555.174 0	1.555 174 0	0.001 555 174	=1 pennyweight
0.056 966 146	0.004 747 178 8	0.003 906 25	1,771.854 4	1.771 845 4	0.001 771 845	=1 advp. dram
0.125	0.010 416 667	0.008 571 429	3,887.935 1	3.887 935 1	0.003 887 935	=1 apoth. dram
0.911 458 3	0.075 954 861	0.062 5	28,349.527	28.349 527	0.028 349 53	=1 avdp. ounce
1	0.083 333 33	0.068 571 43	31,103.481	31.103 481	0.031 103 48	=1 apoth or trop ounce
12	1	0.822 857 1	373,241.77	373.241 77	0.373 241 77	=1 apoth. or troy pound
14.583 333	1.215 277 8	1	453,592.427 7	453.592 427 7	0.453 592 427 7	=1 avdp. pound
0.000 032 150 74	0.000 002 679 23	0.000 002 201 62	1	0.001	0.000 001	=1 milligram
0.032 150 74	0.002 679 23	0.002 204 62	1,000	1	0.001	=1 gram
32.150 742	2.679 228 5	2.204 622 341	1,000,000	1000	1	=1 kilogram

than Avoirdupois Ounces

Long tons	Kilograms	Metric tons	Units
0.000 027 901 79	0.028 349 53	0.000 028 349 53	=1 avoirdupois ounce
0.000 446 428 6	0.453 592 427 7	0.000 453 592 43	=1 avoirdupois pound
0.044 642 86	45.359 243	0.045 359 243	=1 short hundredweight
0.892 857 1	907.184 86	0.907 184 86	=1 short ton
1	1016.047 04	1.016 047 04	=1 long ton
0.000 984 206 4	1	0.001	=1 kilogram
0.984 206 40	1000	1	=1 metric ton

COMPARISON OF METRIC AND CUSTOMARY UNITS FROM 1 TO 9

1. Length

Inches (in.)	Millimeters (mm)	Feet (ft.)	Meters (m)	Yards (yd.)	Meters (m)	Rods (rd.)	Meters (m)	U. S. miles (mi.)	Kilometers (km.)
0.039 37	1	1	0.304 801	1	0.914 402	0.198 838	1	0.621 370	1
0.078 74	2	2	0.609 601	2	1.828 804	0.397 677	2	1.242 740	2
0.118 11	3	3	0.914 402	3	2.743 205	0.596 515	3	1.864 110	3
0.157 48	4	4	1.219 202	4	3.657 607	0.795 354	4	2.485 480	4
0.196 85	5	5	1.524 003	5	4.572 009	0.994 192	5	3.106 850	5
0.236 22	6	6	1.828 804	6	5.486 411	1.193 030	6	3.728 220	6
0.275 59	7	7	2.133 604	7	6.400 813	1.391 869	7	4.349 590	7
0.314 96	8	8	2.438 405	8	7.315 215	1.590 707	8	4.970 960	8
0.354 33	9	9	2.743 205	9	8.229 616	1.789 545	9	5.592 330	9
1	25.4001	3.280 83	1	1.093 611	1	1	5.029 21	1	1.609 347
2	50.8001	6.561 67	2	2.187 222	2	2	10.058 42	2	3.218 694
3	76.2002	9.842 50	3	3.280 833	3	3	15.087 63	3	4.828 042
4	101.6002	13.123 33	4	4.374 444	4	4	20.116 84	4	6.437 389
5	127.0003	16.404 17	5	5.468 056	5	5	25.146 05	5	8.046 736
6	152.4003	19.685 00	6	6.561 667	6	6	30.175 26	6	9.656 083
7	177.8004	22.965 83	7	7.655 278	7	7	35.204 47	7	11.265 431
8	203.2004	26.246 67	8	8.748 889	8	8	40.233 68	8	12.874 778
9	228.6005	29.527 50	9	9.842 500	9	9	45.262 89	9	14.484 125

2. Area

Square inches (sq. in.)	Square centimeters (cm²)	Square feet (sq. ft.)	Square meters (m²)	Square yards (sq. yd.)	Square meters (m²)	Acres (A.)	Hectares (ha)	Square miles (sq. mi.)	Square kilometers (km²)
0.155 00	1	1	0.092 90	1	0.8361	1	0.4047	0.3861	1
0.310 00	2	2	0.185 81	2	1.6723	2	0.8094	0.7722	2
0.465 00	3	3	0.278 71	3	2.5084	3	1.2141	1.1583	3
0.620 00	4	4	0.371 61	4	3.3445	4	1.6187	1.5444	4
0.775 00	5	5	0.464 52	5	4.1807	5	2.0234	1.9305	5
0.930 00	6	6	0.557 42	6	5.0168	6	2.4281	2.3166	6
1.085 00	7	7	0.650 32	7	5.8529	7	2.8328	2.7027	7
1.240 00	8	8	0.743 23	8	6.6890	8	3.2375	3.0888	8
1.395 00	9	9	0.836 13	9	7.5252	9	3.6422	3.4749	9
1	6.452	10.764	1	1.1960	1	2.471	1	1	2.5900
2	12.903	21.528	2	2.3920	2	4.942	2	2	5.1800
3	19.355	32.292	3	3.5880	3	7.413	3	3	7.7700
4	25.807	43.055	4	4.7839	4	9.884	4	4	10.3600
5	32.258	53.819	5	5.9799	5	12.355	5	5	12.9500
6	38.710	64.583	6	7.1759	6	14.826	6	6	15.5400
7	45.161	75.347	7	8.3719	7	17.297	7	7	18.1300
8	51.613	86.111	8	9.5679	8	19.768	8	8	20.7200
9	58.065	96.875	9	10.7639	9	22.239	9	9	23.3100

3. Volume

Cubic inches (cu. in.)	Cubic centimeters (cm³)	Cubic feet (cu. ft.)	Cubic meters (m³)	Cubic yards (cu. yd.)	Cubic meters (m³)	Cubic inches (cu. in.)	Liters (l)	Cubic feet (cu. ft.)	Liters (l)
0.161 02	1	1	0.028 317	1	0.7646	1	0.016 386 7	1	28.316
0.122 05	2	2	0.056 634	2	1.5291	2	0.032 773 4	2	56.633
0 183 07	3	3	0.084 951	3	2.2937	3	0.049 160 2	3	84.949
0 244 09	4	4	0.113 268	4	3.0582	4	0.065 546 9	4	113.265
0.305 12	5	5	0.141 585	5	3.8228	5	0.081 933 6	5	141.581
0.366 14	6	6	0.169 902	6	4.5874	6	0.098 320 3	6	169.898
0.427 16	7	7	0.198 219	7	5.3519	7	0.114 707 0	7	198.214
0.488 19	8	8	0.226 536	8	6.1165	8	0.131 093 8	8	226.530
0.549 21	9	9	0.254 853	9	6.8810	9	0.147 480 5	9	254.846
1	16.3872	35.314	1	1.3079	1	61.025	1	0.035 315	1
2	32.7743	70.629	2	2.6159	2	122.050	2	0.070 631	2
3	49.1615	105.943	3	3.9238	3	183.075	3	0.105 946	3
4	65.5486	141.258	4	5.2318	4	244.100	4	0.141 262	4
5	81.9358	176.572	5	6.5397	5	305.125	5	0.176 577	5
6	98.3230	211.887	6	7.8477	6	366.150	6	0.211 892	6
7	114.7101	247.201	7	9.1556	7	427.175	7	0.247 208	7
8	131.0973	282.516	8	10.4635	8	488.200	8	0.282 523	8
9	147.4845	317.830	9	11.7715	9	549.225	9	0.317 839	9

COMPARISON OF METRIC AND CUSTOMARY UNITS FROM 1 TO 9—*Continued*

4. Capacity—Liquid Measure

U. S. fluid drams (fl. dr.) = Milliliters (ml)	U. S. fluid ounces (fl. oz.) = Milliliters (ml)	U. S. liquid pints (pt.) = Liters (l)	U. S. liquid quarts (qt.) = Liters (l)	U. S. gallons (gal.) = Liters (l)
0.270 52 = **1**	0.033 815 = **1**	**1** = 0.473 17	**1** = 0.946 33	0.264 18 = **1**
0.541 04 = **2**	0.067 629 = **2**	**2** = 0.946 33	**2** = 1.892 67	0.528 36 = **2**
0.811 55 = **3**	0.101 444 = **3**	**3** = 1.419 50	**3** = 2.839 00	0.792 53 = **3**
1.082 07 = **4**	0.135 259 = **4**	**4** = 1.892 67	**4** = 3.785 33	1.056 71 = **4**
1.352 59 = **5**	0.169 074 = **5**	**5** = 2.365 83	**5** = 4.731 67	1.320 89 = **5**
1.623 11 = **6**	0.202 888 = **6**	**6** = 2.839 00	**6** = 5.678 00	1.585 07 = **6**
1.893 63 = **7**	0.236 703 = **7**	**7** = 3.312 17	**7** = 6.624 33	1.849 24 = **7**
2.164 14 = **8**	0.270 518 = **8**	**8** = 3.785 33	**8** = 7.570 66	2.113 42 = **8**
2.434 66 = **9**	0.304 333 = **9**	**9** = 4.258 50	**9** = 8.517 00	2.377 60 = **9**
1 = 3.6966	**1** = 29.573	2.1134 = **1**	1.056 71 = **1**	**1** = 3.785 33
2 = 7.3932	**2** = 59.146	4.2268 = **2**	2.113 42 = **2**	**2** = 7.570 66
3 = 11.0898	**3** = 88.719	6.3403 = **3**	3.170 13 = **3**	**3** = 11.356 00
4 = 14.7865	**4** = 118.292	8.4537 = **4**	4.226 84 = **4**	**4** = 15.141 33
5 = 18.4831	**5** = 147.865	10.5671 = **5**	5.283 55 = **5**	**5** = 18.926 66
6 = 22.1797	**6** = 177.437	12.6805 = **6**	6.340 26 = **6**	**6** = 22.711 99
7 = 25.8763	**7** = 207.010	14.7939 = **7**	7.396 97 = **7**	**7** = 26.497 33
8 = 29.5729	**8** = 236.583	16.9074 = **8**	8.453 68 = **8**	**8** = 30.282 66
9 = 33.2695	**9** = 266.156	19.0208 = **9**	9.510 39 = **9**	**9** = 34.067 99

5. Capacity—Dry Measure

U. S. dry quarts (qt.) = Liters (l)	U. S. pecks (pk.) = Liters (l)	U. S. pecks (pk.) = Dekaliters (dkl)	U. S. bushels (bu.) = Hectoliters (hl)	U. S. bushels per acre = Hectoliters per hectare
0.9081 = **1**	0.113 51 = **1**	**1** = 0.8810	**1** = 0.352 38	**1** = 0.8708
1.8162 = **2**	0.227 03 = **2**	**2** = 1.7619	**2** = 0.704 77	**2** = 1.7415
2.7243 = **3**	0.340 54 = **3**	**3** = 2.6429	**3** = 1.057 15	**3** = 2.6123
3.6324 = **4**	0.454 05 = **4**	**4** = 3.5238	**4** = 1.409 53	**4** = 3.4830
4.5405 = **5**	0.567 56 = **5**	**5** = 4.4048	**5** = 1.761 92	**5** = 4.3538
5.4486 = **6**	0.681 08 = **6**	**6** = 5.2857	**6** = 2.114 30	**6** = 5.2245
6.3567 = **7**	0.794 59 = **7**	**7** = 6.1667	**7** = 2.466 68	**7** = 6.0953
7.2648 = **8**	0.908 10 = **8**	**8** = 7.0477	**8** = 2.819 07	**8** = 6.9660
8.1729 = **9**	1 021 61 = **9**	**9** = 7.9286	**9** = 3.171 45	**9** = 7.8368
1 = 1.1012	**1** = 8.810	1.1351 = **1**	2.8378 = **1**	1.1484 = **1**
2 = 2.2024	**2** = 17.619	2.2703 = **2**	5.6756 = **2**	2.2969 = **2**
3 = 3.3036	**3** = 26.429	3.4054 = **3**	8.5135 = **3**	3.4453 = **3**
4 = 4.4048	**4** = 35.238	4.5405 = **4**	11.3513 = **4**	4.5937 = **4**
5 = 5.5060	**5** = 44.048	5.6756 = **5**	14.1891 = **5**	5.7421 = **5**
6 = 6.6072	**6** = 52.857	6.8108 = **6**	17.0269 = **6**	6.8906 = **6**
7 = 7.7084	**7** = 61.667	7.9459 = **7**	19.8647 = **7**	8.0390 = **7**
8 = 8.8096	**8** = 70.477	9.0810 = **8**	22.7026 = **8**	9.1874 = **8**
9 = 9.9108	**9** = 79.286	10.2161 = **9**	25.5404 = **9**	10.3359 = **9**

6. Mass

Grains (gr.) = Grams (g)	Apothecaries' drams (dr. ap. or ℨ) = Grams (g)	Troy ounces (oz. t.) = Grams (g)	Avoirdupois ounces (oz. avdp.) = Grams (g)	Avoirdupois pounds (lb. avdp.) = Kilograms (kg)
1 = 0.064 799	0.257 21 = **1**	0.032 151 = **1**	0.035 274 = **1**	**1** = 0.453 59
2 = 0.129 598	0.514 41 = **2**	0.064 301 = **2**	0.070 548 = **2**	**2** = 0.907 18
3 = 0.194 397	0.771 62 = **3**	0.096 452 = **3**	0.105 822 = **3**	**3** = 1.360 78
4 = 0.259 196	1.028 82 = **4**	0.128 603 = **4**	0.141 096 = **4**	**4** = 1.814 37
5 = 0.323 995	1.286 03 = **5**	0.160 754 = **5**	0.176 370 = **5**	**5** = 2.267 96
6 = 0.388 794	1.543 24 = **6**	0.192 904 = **6**	0.211 644 = **6**	**6** = 2.721 55
7 = 0.453 592	1.800 44 = **7**	0.225 055 = **7**	0.246 918 = **7**	**7** = 3.175 15
8 = 0.518 391	2.057 65 = **8**	0.257 206 = **8**	0.282 192 = **8**	**8** = 3.628 74
9 = 0.583 190	2.314 85 = **9**	0.289 357 = **9**	0.317 466 = **9**	**9** = 4.082 33
15.4324 = **1**	**1** = 3.8879	**1** = 31.103	**1** = 28.350	2.204 62 = **1**
30.8647 = **2**	**2** = 7.7759	**2** = 62.207	**2** = 56.699	4.409 24 = **2**
46.2971 = **3**	**3** = 11.6638	**3** = 93.310	**3** = 85.049	6.613 87 = **3**
61.7294 = **4**	**4** = 15.5517	**4** = 124.414	**4** = 113.398	8.818 49 = **4**
77.1618 = **5**	**5** = 19.4397	**5** = 155.517	**5** = 141.748	11.023 11 = **5**
92.5941 = **6**	**6** = 23.3276	**6** = 186.621	**6** = 170.097	13.227 73 = **6**
108.0265 = **7**	**7** = 27.2155	**7** = 217.724	**7** = 198.447	15.432 36 = **7**
123.4589 = **8**	**8** = 31.1035	**8** = 248.828	**8** = 226.796	17.636 98 = **8**
138.8912 = **9**	**9** = 34.9914	**9** = 279.931	**9** = 255.146	19.841 60 = **9**

EQUIVALENT UNITS OF MEASUREMENT, COMMONLY USED IN THE PETROLEUM INDUSTRY

Units	Cubic feet	Cubic inches	U. S. gallons	Imperial gallons	Liters
Cubic foot =	1	1,728	7.480 519	6.232 103	28.317 02
Cubic inch =	0.000 578 7	1	0.004 329 0	0.003 606 5	0.016 387 2
U. S. gallon =	0.133 680 6	231	1	0.833 110 9	3.785 332
Imperial gallon =	0.160 459 5	277.274	1.200 320	1	4.543 734
Liter =	0.035 314 5	61.025 38	0.264 170 5	0.220 083 3	1
Petroleum barrel =	5.614 583	9,702	42	34.990 66	158.988 2
Pound (avdp.) =	0.016 033 3	27.705 63	0.119 937 8	0.099 921 5	0.454 016 6
Kilogram =	0.035 347 5	61.080 45	0.264 417 5	0.220 289 1	1.000 935
Metric ton =	35.347 48	61,080.45	264.417 5	220.289 1	1000.935
Pood (Russian) =	0.578 703 7	1,000	4.329 004	3.606 541	16.387 16
Barrel (Canada) =	5.616 082 5	9,704	42.011 2	35	159.030 7

Units	Petroleum barrels	Pounds (avdp.)	Kilograms	Metric tons
Cubic foot =	0.178 107 6	62.37	28.290 56	0.028 290 6
Cubic inch =	0.000 103 1	0.036 093 8	0.016 371 9	0.000 016 371 851 68
U. S. gallon =	0.023 809 5	8.337 656	3.781 898	0.003 789
Imperial gallon =	0.028 579 1	10.007 86	4.539 489	0.004 539 488 803
Liter =	0.006 289 8	2.202 563	0.999 065 7	0.000 999 1
Petroleum barrel =	1	350.181 6	158.839 7	0.158 839 705 1
Pound (avdp.) =	0.002 855 7	1	0.453 592 4	0.000 453 6
Kilogram =	0.006 295 7	2.204 622	1	0.001 000 0
Metric ton =	6.295 655	2204.622	1000	1
Pood (Russian) =	0.103 071 5	36.093 75	16.371 85	0.016 371 851 7
Barrel (Canada) =	1.002 685	350.275 1	158.882 1	0.158 882 108 105

Water is taken at 39.1 ° F.

EQUIVALENT VALUES OF ELECTRICAL, MECHANICAL AND HEAT UNITS

Units	Equivalent value in other units
1 foot-pound =	1.3558 joules 0.13826 kg.m. 0.0000003766 Kw. hour 0.0012861 heat-unit 0.0000005 H.P. hour
1 joule =	1 watt second 0.000000278 Kw. hour 0.10197 kg.m. 0.0009486 heat-units 0.73756 ft.-lb.
1 watt =	1 joule per second 0.001341 H.P. 3.415 heat units per hour 0.73756 ft.-lb. per second 0.0035 lb. water evap. per hour 44.254 ft.-lbs. per minute
1 watt per sq. in. =	8.20 heat-units per sq. ft. per minute 6,373 ft.-lbs. per sq. ft. per minute 0.1931 H.P. per square foot
1 kilogram meter =	7.233 ft.-lbs. 0.000003653 H.P. hour 0.000002724 Kw. hour 0.009302 heat-unit
1 heat-unit =	1,054.2 watt seconds 777.54 ft.-lbs. 107.5 kilogram meters 0.0002928 Kw. hour 0.0003927 H.P. hour 0.0000685 lb. carbon oxidised 0.001030 lb. water evaporated from and at 212° F.
1 heat-unit per sq. ft. per min. =	0.1220 watt per square inch 0.01757 Kw. per square foot 0.02356 H.P. per square foot
1 horse-power =	745.7 watts 0.7457 Kw. 33,000 ft.-lbs. per minute 550 ft.-lbs. per second 2,546.5 heat-units per hour 42.44 heat-units per minute 0.707 heat-unit per second 0.174 carbon oxidised per hour 2.62 lbs. water evap. per hr. from and at 212° F.
1 horse-power hour =	0.7457 Kw. hour 1,980,000 ft.-lbs. 2,546.5 heat-units 273,740 kg.m. 0.174 lb. carbon oxidised with perfect efficiency 2.62 lbs. water evap. from and at 212° F. 17.0 lbs. water raised from 62° F. to 212° F.
1 kilowatt =	1,000 watts 1.3410 H. P. 2,655,200 ft.-lbs. per hour 44,254 ft.-lbs. per minute 737.56 ft.-lbs. per second 3,415 heat-units per hour 56.92 heat-units per minute 0.9486 heat-units per second 0.234 lb. carbon oxidised per hour 3.52 lbs. water evap. per hr. from and at 212° F.
1 kilowatt hour =	1,000 watt hours 1.341 H. P. hours 2,655,200 ft.-lbs. 3,600,000 joules 3,415 heat-units 367,100 kilogram meters 0.234 lb. carbon oxidised with perfect efficiency 3.52 lbs. water evap. from and at 212° F. 22.77 lbs. of water raised from 62° to 212° F.
1 lb. carbon oxidised with perfect efficiency =	14,600 heat-units 1.11 lbs. anthracite coal oxidised 2.5 lbs. dry wood oxidised 22 cu. ft. illuminating-gas 4.275 Kw. hours 5.733 H.P. hours 11,352,000 ft.-lbs. 15.05 lbs. of water evap. from and at 212° F.
1 lb. water evap. from and at 212° F. =	0.2841 Kw. hour 0.3811 H.P. hour 970.4 heat-units 104,320 kg.m. 1,023,000 joules 754,525 ft.-lbs. 0.066466 lb. carbon oxidised

CAPACITY OF TANKS AND PIPES

Gallons in Cylindrical Tanks

Depth in feet	Diameters in Feet: 5	6	7	8	9	10	12	14	16	18	20	25	30	35	40	45	50
1	147	212	288	376	476	588	846	1,152	1,504	1,904	2,350	3,672	5,288	7,197	9,400	11,897	14 688
5	734	1,058	1,439	1,880	2,379	2,938	4,230	5,758	7,520	9,518	11,751	18,360	26,438	35,986	47,001	59,486	73,440
6	881	1,269	1,727	2,256	2,855	3,525	5,076	6,909	9,025	11,422	14,101	22,032	31,726	43,183	56,402	71,383	88,128
7	1,028	1,481	2,015	2,632	3,331	4,113	5,922	8,061	10,529	13,325	16,451	25,704	37,014	50,380	65,802	83,281	102,816
8	1,175	1,692	2,303	3,008	3,807	4,700	6,768	9,212	12,033	15,229	18,801	29,376	42,301	57,577	75,202	95,178	117,504
9	1,322	1,904	2,591	3,384	4,283	5,288	7,614	10,364	13,537	17,132	21,151	33,048	47,589	64,774	84,603	107,075	132,192
10	1,469	2,115	2,879	3,760	4,759	5,875	8,460	11,515	15,041	19,036	23,501	36,720	52,877	71,971	94,003	118,972	146,880
12	1,762	2,538	3,455	4,512	5,711	7,050	10,152	13,818	18,049	22,843	28,201	44,064	63,452	86,365	112,803	142,767	176,256
14	2,056	2,961	4,030	5,264	6,662	8,225	11,844	16,121	21,033	26,650	32,901	51,408	74,027	100,759	131,604	166,561	205,631
16	2,350	3,384	4,606	6,016	7,614	9,400	13,536	18,424	24,066	30,458	37,602	58,752	84,603	115,154	150,405	190,356	235,007
18	2,644	3,807	5,182	6,768	8,566	10,575	15,228	20,727	27,074	34,265	42,302	66,096	95,178	129,548	169,205	214,150	264,383
20	2,938	4,230	5,758	7,520	9,518	11,750	16,921	23,030	30,082	38,072	47,002	73,440	105,753	143,942	188,006	237,945	293,759
25	3,672	5,288	7,197	9,400	11,897	14,688	21,151	28,788	37,603	47,590	58,753	91,800	132,192	179,928	235,007	297,431	367,199
30	4,406	6,345	8,636	11,280	14,277	17,626	25,381	34,545	45,123	57,108	70,503	110,160	158,630	215,913	282,009	356,917	440,639
35	5,141	7,403	10,076	13,160	16,656	20,563	29,611	40,303	52,643	66,626	82,254	128,520	185,068	251,899	329,010	416,404	514,079
40	5,875	8,460	11,515	15,040	19,036	23,501	33,841	46,060	60,164	76,144	94,004	146,880	211,507	287,884	376,012	475,890	587,518
45	6,610	9,518	12,955	16,920	21,415	26,440	38,071	51,818	67,685	85,662	105,755	165,239	237,945	323,870	423,013	535,376	660,958
50	7,344	10,576	14,394	18,800	23,794	29,376	42,301	57,575	75,205	95,180	117,505	183,600	264,383	359,855	470,015	594,862	734,398
60	8,813	12,691	17,273	22,561	28,553	35,251	50,762	69,090	90,246	114,216	141,006	220,319	317,260	431,826	564,017	713,835	881,278
70	10,283	14,806	20,152	26,321	33,312	41,126	59,222	80,605	105,287	133,252	164,507	257,039	370,137	503,797	658,020	832,807	1,028,157
80	11,750	16,921	23,031	30,081	38,071	47,002	67,682	92,120	120,328	152,288	188,008	293,759	423,013	575,768	752,024	951,780	1,175,037
90	13,219	19,036	25,909	33,841	42,830	52,877	76,143	103,635	135,369	171,324	211,509	330,479	475,890	647,739	846,027	1,070,752	1,321,916
100	14,688	21,151	28,788	37,601	47,589	58,752	84,603	115,150	150,410	190,360	235,010	367,199	528,767	719,710	940,030	1,189,725	1,468,796

$$1 \text{ gallon} = 231 \text{ cubic inches} = \frac{1 \text{ cubic foot}}{7.4705} = 0.13368 \text{ cubic foot.}$$

Water in Pipes

Quantity of water contained in 1 linear foot of standard wrought pipe. Number of linear feet to contain 1 cubic foot weight of pipe and diameters.

231 cubic inches = 1 gallon
1 cubic foot = 7.4805 gallons
1 cubic foot = 62.4 pounds water
1 gallon = 0.13368 cubic foot
1 gallon = 8.3353 pounds

Size	Diameter		Weight of pipe per linear foot	Length of pipe containing 1 cubic foot	U. S. gallons contained in 1 linear foot of pipe	Water contained in 1 linear foot of pipe
	External	Internal				
Inches	Inches	Inches	Pounds	Linear feet	Gallons	Pounds
1/8	0.405	0.269	0.24	2533.8	0.0030	0.0246
1/4	0.540	0.364	0.42	1383.8	0.0054	0.0451
3/8	0.675	0.493	0.56	754.36	0.0099	0.0827
1/2	0.840	0.622	0.84	473.91	0.0158	0.1316
3/4	1.050	0.824	1.12	270.03	0.0277	0.2309
1	1.315	1.049	1.67	166.62	0.0449	0.3742
1 1/4	1.660	1.380	2.24	96.275	0.0777	0.6477
1 1/2	1.900	1.610	2.68	70.733	0.1058	0.8816
2	2.375	2.067	3.61	42.913	0.1743	1.4530
2 1/2	2.875	2.469	5.74	30.077	0.2487	2.0732
3	3.500	3.068	7.54	19.479	0.3840	3.2012
3 1/2	4.000	3.548	9.00	14.565	0.5136	4.2812
4	4.500	4.026	10.66	11.312	0.6613	5.5125
4 1/2	5.000	4.506	12.49	9.0301	0.8284	6.9053
5	5.563	5.047	14.50	7.1979	1.0393	8.6629
6	6.625	6.065	18.76	4.9844	1.5008	12.5101
7	7.625	7.023	23.27	3.7173	2.0124	16.7743
8	8.625	8.070	25.00	2.8784	2.5988	21.6627
9	9.625	8.941	33.70	2.2935	3.2616	27.1876
10	10.750	10.140	35.00	1.8262	4.0963	34.1456
11	11.750	11.000	45.00	1.5153	4.9368	41.1513
12	12.750	12.090	45.00	1.2732	5.8752	48.9735
13	14.000	13.250	56.10	1.0443	7.1629	59.7077
14	15.000	14.250	60.70	0.90291	8.2849	69.0603
15	16.000	15.250	64.90	0.78838	9.4885	79.0931
	18.000	17.250	70.65	0.61616	12.1405	101.1992
	20.000	19.250	78.67	0.49478	15.1189	126.0270
	22.000	21.250	86.68	0.40603	18.4237	153.5736
	24.000	23.250	94.70	0.33918	22.0549	183.8419

Capacities of Rectangular Tanks in U. S. Gallons, for Each Foot in Depth

1 cubic foot = 7.4805 U. S. gallons

Width of tank		Length of Tank										
		Feet 2	Ft. In. 2 6	Feet 3	Ft. In. 3 6	Feet 4	Ft. In. 4 6	Feet 5	Ft. In. 5 6	Feet 6	Ft. In. 6 6	Feet 7
Ft.	In.											
2		29.92	37.40	44.88	52.36	59.84	67.32	74.81	82.29	89.77	97.25	104.73
2	6	....	46.75	56.10	65.45	74.80	84.16	93.51	102.86	112.21	121.56	130.91
3		....	.....	67.32	78.54	89.77	100.99	112.21	123.43	134.65	145.87	157.09
3	6	....	.....	.....	91.64	104.73	117.82	130.91	144.00	157.09	170.18	183.27
4		....	.....	.....	.....	119.69	134.65	149.61	164.57	179.53	194.49	209.45
4	6	....	.....	.....	.....	.....	151.48	168.31	185.14	201.97	218.80	235.62
5		....	.....	.....	.....	.....	.....	187.01	205.71	224.41	243.11	261.82
5	6	....	.....	.....	.....	.....	.....	.....	226.28	246.86	267.43	288.00
6		....	.....	.....	.....	.....	.....	.....	.....	269.30	291.74	314.18
6	6	....	.....	.....	.....	.....	.....	.....	.....	.....	316.05	340.36
7		....	.....	.....	.....	.....	.....	.....	.....	.....	.....	366.54

Width of tank		Length of Tank									
		Ft. In. 7 6	Feet 8	Ft. In. 8 6	Feet 9	Ft. In. 9 6	Feet 10	Ft. In. 10 6	Feet 11	Ft. In. 11 6	Feet 12
Ft.	In.										
2		112.21	119.69	127.17	134.65	142.13	149.61	157.09	164.57	172.05	179.53
2	6	140.26	149.61	158.96	168.31	177.66	187.01	196.36	205.71	215.06	224.41
3		168.31	179.53	190.75	202.97	213.19	224.41	235.63	246.86	258.07	269.30
3	6	196.36	209.45	222.54	235.63	248.73	261.82	274.90	288.00	301.09	314.18
4		224.41	239.37	254.34	269.30	284.26	299.22	314.18	329.14	344.10	359.06
4	6	252.47	269.30	286.13	302.96	319.79	336.62	353.45	370.28	387.11	403.94
5		280.52	299.22	317.92	336.62	355.32	374.03	392.72	411.43	430.13	448.83
5	6	308.57	329.14	349.71	370.28	390.85	411.43	432.00	452.57	473.14	493.71
6		336.62	359.06	381.50	403.94	426.39	448.83	471.27	493.71	516.15	538.59
6	6	364.67	388.98	413.30	437.60	461.92	486.23	510.54	534.85	559.16	583.47
7		392.72	418.91	445.09	471.27	497.45	523.64	549.81	575.99	602.18	628.36
7	6	420.78	448.83	476.88	504.93	532.98	561.04	589.08	617.14	645.19	673.24
8		.....	478.75	508.67	538.59	568.51	598.44	628.36	658.28	688.20	718.12
8	6	.....	.....	540.46	572.25	604.05	635.84	667.63	699.42	731.21	763.00
9		.....	.....	.....	605.92	639.58	673.25	706.90	740.56	774.23	807.89
9	6	.....	.....	.....	......	675.11	710.65	746.17	781.71	817.24	852.77
10		.....	.....	.....	......	......	748.05	785.45	822.86	860.26	897.66
10	6	.....	.....	.....	......	......	......	824.73	864.00	903.26	942.56
11		.....	.....	.....	......	......	......	......	905.14	946.27	987.43
11	6	.....	.....	.....	......	......	......	......	......	989.29	1032.30
12		.....	.....	.....	......	......	......	......	......	......	1077.20

IRON AND STEEL

Weights of Iron and Steel Standard Gages

No. of gage	U. S. Standard Gage: Thickness in inches, Fractions	U. S. Standard Gage: Thickness in inches, Decimals	U. S. Standard Gage: Weight per square foot, Iron	U. S. Standard Gage: Weight per square foot, Steel	Birmingham Wire Gage: No. of gage	Birmingham Wire Gage: Thickness in inches	Birmingham Wire Gage: Weight per square foot, Iron	Birmingham Wire Gage: Weight per square foot, Steel
7-0's	1/2	0.5	20.00	20.4				
6-0's	15/32	.46875	18.75	19.125				
5-0's	7/16	.4375	17.50	17.85				
0000	13/32	.40625	16.25	16.575	0000	0.454	18.22	18.46
000	3/8	.375	15	15.30	000	.425	17.05	17.28
00	11/32	.34375	13.75	14.025	00	.38	15.25	15.45
0	5/16	.3125	12.50	12.75	0	.34	13.64	13.82
1	9/32	.28125	11.25	11.475	1	.3	12.04	12.20
2	17/64	.265625	10.625	10.8375	2	.284	11.40	11.55
3	1/4	.25	10	10.2	3	.259	10.39	10.53
4	15/64	.234375	9.375	9.5625	4	.238	9.55	9.68
5	7/32	.21875	8.75	8.925	5	.22	8.83	8.95
6	13/64	.203125	8.125	8.2875	6	.203	8.15	8.25
7	3/16	.1875	7.5	7.65	7	.18	7.22	7.32
8	11/64	.171875	6.875	7.0125	8	.165	6.62	6.71
9	5/32	.15625	6.25	6.375	9	.148	5.94	6.02
10	9/64	.140625	5.625	5.7375	10	.134	5.38	5.45
11	1/8	.125	5	5.1	11	.12	4.82	4.88
12	7/64	.109375	4.375	4.4625	12	.109	4.37	4.43
13	3/32	.09375	3.75	3.825	13	.095	3.81	3.86
14	5/64	.078125	3.125	3.1875	14	.083	3.33	3.37
15	9/128	.0703125	2.8125	2.86875	15	.072	2.89	2.93
16	1/16	.0625	2.5	2.55	16	.065	2.61	2.64
17	9/160	.05625	2.25	2.295	17	.058	2.33	2.36
18	1/20	.05	2	2.04	18	.049	1.97	1.99
19	7/160	.04375	1.75	1.785	19	.042	1.69	1.71
20	3/80	.0375	1.50	1.53	20	.035	1.40	1.42
21	11/320	.034375	1.375	1.4025	21	.032	1.28	1.30
22	1/32	.03125	1.25	1.275	22	.028	1.12	1.14
23	9/320	.028125	1.125	1.1475	23	.025	1.00	1.02
24	1/40	.025	1	1.02	24	.022	0.883	0.895
25	7/320	.021875	0.865	0.8925	25	.02	.803	.813
26	3/160	.01875	.75	.765	26	.018	.722	.732
27	11/640	.0171875	.6875	.70125	27	.016	.642	.651
28	1/64	.015625	.625	.6375	28	.014	.562	.569
29	9/640	.0140625	.5625	.57375	29	.013		
30	1/80	.0125	.5	.51	30	.012		
31	7/640	.0109375	.4375	.44625	31	.01		
32	13/1280	.01015625	.40625	.414375	32	.009		
33	3/320	.009375	.375	.3825	33	.008		
34	11/1280	.00859375	.34375	.350625	34	.007		
35	5/640	.0078125	.3125	.31875	35	.005		
36	9/1280	.00703125	.28125	.286875	36	.004		
37	17/2560	.00664062	.265625	.2709375				
38	1/160	.00625	.25	.255				

Sheet mills roll iron and steel sheets to U. S. standard gage. Plate mills usually roll to Birmingham wire gage, unless otherwise ordered. Bands and hoops, cold rolled strip steel and spring steel are rolled to Birmingham wire gage.

	Iron	Steel
Specific gravity....................	7.7	7.854
Weight per cubic foot................	480	489.6
Weight per cubic inch................	0.2778	0.2833

As there are many different gages in use, and even the thicknesses of a certain specified gage, as adopted by different manufacturers, may not be exactly the same, orders for sheets and wires should always state the weight per square foot, or the thickness in thousandths of an inch.

Standard Gages

Equivalents in decimals of an inch

No. of gage	Thickness in Decimals of an Inch								
	Birmingham wire (B. W. G.), also Stubs iron wire	Brown & Sharpe or American wire	United States standard plate iron and steel, 1893	British Imperial standard wire (S. W. G.), 1884	American Steel & wire, formerly Washburn & Moen, Roebling	Trenton Iron Co.	Stubs steel wire	Paris gage (J. de P.)	British standard "BG." gage 1914, for iron and steel sheets and hoops
7–0's	......	......	0.500	0.500	....	.....	.....	.....	0.6666
6–0's	......	0.580	.46875	.464	....	.....	.....	.....	.625
5–0's	......	.5165	.4375	.432	....	0.45	.....	.....	.5883
4–0's	0.454	.46	.40625	.400	0.3938	.40	.....	.....	.5416
3–0's	.425	.40964	.375	.372	.3625	.36	.....	.....	.500
2–0's	.380	.3648	.34375	.348	.3310	.33	.....	0.0157	.4452
0	.340	.32486	.3125	.324	.3065	.305	.....	.0196	.3964
1	.300	.2893	.28125	.300	.2830	.285	0.227	.0236	.3532
2	.284	.25763	.265625	.276	.2625	.265	.219	.0275	.3147
3	.259	.22942	.25	.252	.2437	.245	.212	.0314	.2804
4	.238	.20431	.234375	.232	.2253	.225	.207	.0354	.250
5	.220	.18194	.21875	.212	.2070	.205	.204	.0393	.2225
6	.203	.16202	.203125	.192	.1920	.190	.201	.0433	.1981
7	.180	.14428	.1875	.176	.1770	.175	.199	.0472	.1764
8	.165	.12849	.171875	.160	.1620	.160	.197	.0512	.1570
9	.148	.11443	.15625	.144	.1483	.145	.194	.0551	.1398
10	.134	.10189	.140625	.128	.1350	.130	.191	.0590	.1250
11	.120	.090742	.125	.116	.1205	.1175	.188	.0630	.1113
12	.109	.080808	.109375	.104	.1055	.1050	.185	.0708	.0991
13	.095	.071961	.09375	.092	.0915	.0925	.182	.0787	.0882
14	.083	.064084	.078125	.080	.0800	.0800	.180	.0866	.0785
15	.072	.057068	.0703125	.072	.0720	.0700	.178	.0944	.0699
16	.065	.05082	.0625	.064	.0625	.0610	.175	.1062	.0625
17	.058	.045257	.05625	.056	.0540	.0525	.172	.1181	.0556
18	.049	.040303	.05	.048	.0475	.0450	.168	.1388	.0495
19	.042	.03589	.04375	.040	.0410	.0400	.164	.1535	.0440
20	.035	.031961	.0375	.036	.0348	.0350	.161	.1732	.0392
21	.032	.028462	.034375	.032	.03175	.0310	.157	.1929	.0349
22	.028	.025347	.03125	.028	.0286	.0280	.155	.2126	.03125
23	.025	.022571	.028125	.024	.0258	.0250	.153	.2322	.02782
24	.022	.0201	.025	.022	.0230	.0225	.151	.2520	.02476
25	.020	.0179	.021875	.020	.0204	.0200	.148	.2756	.02204
26	.018	.01594	.01875	.018	.0181	.0180	.146	.2914	.01961
27	.016	.014195	.0171875	.0164	.0173	.0170	.143	.3228	.01745
28	.014	.012641	.015625	.0148	.0162	.0160	.139	.3462	.015625
29	.013	.011257	.0140625	.0136	.0150	.0150	.134	.3700	.0139
30	.012	.010025	.0125	.0124	.0140	.0140	.127	.3937	.0123
31	.010	.008928	.0109375	.0116	.0132	.0130	.120	.....	.0110
32	.009	.00795	.01015625	.0108	.0128	.0120	.115	.....	.0098
33	.008	.00708	.009375	.0100	.0118	.0110	.112	.....	.0087
34	.007	.006304	.00859375	.0092	.0104	.0100	.110	.....	.0077
35	.005	.005614	.0078125	.0084	.0095	.0095	.108	.....	.0069
36	.004	.005	.00703125	.0076	.0090	.0090	.106	.....	.0061
37	......	.004453	.006640625	.0068	....	.0085	.103	.....	.0054
38	......	.003965	.00625	.0060	....	.0080	.101	.....	.0048
39	......	.003531	....	.0052	....	.0075	.099	.....	.0043
40	......	.003144	....	.0048	....	.0070	.097	.....	.00386
41	......	......	....	.0044	....	.....	.095	.....	.00343
42	......	......	....	.004	....	.....	.092	.....	.00306
43	......	......	....	.0036	....	.....	.088	.....	.00272
44	......	......	....	.0032	....	.....	.085	.....	.00242
45	......	......	....	.0028	....	.....	.081	.....	.00215
46	......	......	....	.0024	....	.....	.079	.....	.00192
47	......	......	....	.002	....	.....	.077	.....	.00170
48	......	......	....	.0016	....	.....	.075	.....	.00152
49	......	......	....	.0012	....	.....	.072	.....	.00135
50	......	......	....	.001	....	.....	.065	.....	.00120

Weight of Plate Iron, per Linear Foot, in Pounds

(Based on 480 pounds per cubic foot. For steel add 2 per cent)

Width in inches	Thickness in Inches															
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
12	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50	40.00
13	2.71	5.42	8.13	10.83	13.54	16.25	18.96	21.67	24.38	27.08	29.79	32.50	35.21	37.92	40.63	43.33
14	2.92	5.83	8.75	11.67	14.58	17.50	20.42	23.33	26.25	29.17	32.08	35.00	37.92	40.83	43.75	46.67
15	3.13	6.25	9.38	12.50	15.63	18.75	21.88	25.00	28.13	31.25	34.38	37.50	40.63	43.75	46.88	50.00
16	3.33	6.67	10.00	13.33	16.67	20.00	23.33	26.67	30.00	33.33	36.67	40.00	43.33	46.67	50.00	53.33
17	3.54	7.08	10.63	14.17	17.71	21.25	24.79	28.33	31.88	35.42	38.96	42.50	46.05	49.59	53.13	56.67
18	3.75	7.50	11.25	15.00	18.75	22.50	26.25	30.00	33.75	37.50	41.25	45.00	48.75	52.50	56.25	60.00
19	3.96	7.92	11.87	15.83	19.79	23.75	27.71	31.67	35.67	39.58	43.54	47.50	51.45	55.41	59.37	63.33
20	4.17	8.33	12.50	16.67	20.83	25.00	29.17	33.33	37.50	41.67	45.83	50.00	54.17	58.33	62.50	66.67
21	4.38	8.75	13.13	17.50	21.88	26.25	30.63	35.00	39.38	43.75	48.13	52.50	56.88	61.25	65.63	70.00
22	4.58	9.17	13.75	18.33	22.92	27.50	32.08	36.67	41.25	45.83	50.42	55.00	59.58	64.17	68.75	73.33
23	4.79	9.58	14.38	19.17	23.96	28.75	33.54	38.33	43.13	47.92	52.71	57.50	62.30	67.09	71.88	76.67
24	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00	65.00	70.00	75.00	80.00
25	5.21	10.42	15.62	20.83	26.04	31.25	36.46	41.67	46.88	52.08	57.29	62.50	67.70	72.91	78.13	83.33
26	5.42	10.83	16.25	21.67	27.08	32.50	37.92	43.33	48.75	54.17	59.58	65.00	70.42	75.83	81.25	86.67
27	5.63	11.25	16.88	22.50	28.13	33.75	39.38	45.00	50.63	56.25	61.88	67.50	73.13	78.75	84.38	90.00
28	5.83	11.67	17.50	23.33	29.17	35.00	40.83	46.67	52.50	58.33	64.17	70.00	75.84	81.67	87.50	93.33
29	6.04	12.08	18.13	24.17	30.21	36.25	42.29	48.33	54.38	60.42	66.46	72.50	78.55	84.59	90.63	96.67
30	6.25	12.50	18.75	25.00	31.25	37.50	43.75	50.00	56.25	62.50	68.75	75.00	81.25	87.50	93.75	100.0
32	6.67	13.33	20.00	26.67	33.33	40.00	46.67	53.33	60.00	66.67	73.33	80.00	86.67	93.33	100.0	106.7
34	7.08	14.17	21.25	28.33	35.42	42.50	49.58	56.67	63.75	70.83	77.91	85.00	92.08	99.17	106.3	113.3
36	7.50	15.00	22.50	30.00	37.50	45.00	52.50	60.00	67.50	75.00	82.50	90.00	97.50	105.0	112.5	120.0
38	7.92	15.83	23.75	31.67	39.59	47.50	55.42	63.33	71.25	79.17	87.09	95.00	102.9	110.8	118.8	126.7
40	8.33	16.67	25.00	33.33	41.67	50.00	58.33	66.67	75.00	83.33	91.67	100.0	108.3	116.7	125.0	133.3
42	8.75	17.50	26.25	35.00	43.75	52.50	61.25	70.00	78.75	87.50	96.25	105.0	113.7	122.5	131.3	140.0
44	9.17	18.33	27.50	36.67	45.84	55.00	64.17	73.33	82.50	91.67	100.8	110.0	119.2	128.3	137.5	146.7
46	9.58	19.17	28.75	38.33	47.92	57.50	67.08	76.67	86.25	95.83	105.4	115.0	124.6	134.2	143.8	153.3
48	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.0	110.0	120.0	130.0	140.0	150.0	160.0
50	10.42	20.83	31.25	41.67	52.08	62.50	72.91	83.33	93.75	104.2	114.6	125.0	135.4	145.8	156.3	166.7
52	10.83	21.67	32.50	43.33	54.17	65.00	75.83	86.67	97.50	108.3	119.2	130.0	140.8	151.7	162.5	173.3
54	11.25	22.50	33.75	45.00	56.25	67.50	78.75	90.00	101.3	112.5	123.8	135.0	146.3	157.5	168.8	180.0
56	11.67	23.33	35.00	46.67	58.33	70.00	81.66	93.33	105.0	116.7	128.3	140.0	151.7	163.3	175.0	186.7
58	12.08	24.17	36.25	48.33	60.42	72.50	84.58	96.67	108.8	120.8	132.9	145.0	157.1	169.2	181.3	193.3
60	12.50	25.00	37.50	50.00	62.50	75.00	87.50	100.00	121.5	125.0	137.5	150.0	162.5	175.0	187.5	200.0

WEIGHTS OF FLAT ROLLED IRON IN POUNDS PER LINEAR FOOT—WIDTHS FROM 1 TO 12 INCHES

(Iron weighing 480 pounds per cubic foot. For steel add 2 per cent)

Thickness in inches	Widths in Inches															
	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾
1/16	0.208	0.260	0.313	0.365	0.417	0.469	0.521	0.573	0.625	0.677	0.729	0.781	0.833	0.885	0.938	0.990
1/8	0.417	0.521	0.625	0.729	0.833	0.938	1.04	1.15	1.25	1.35	1.46	1.56	1.67	1.77	1.88	1.98
3/16	0.625	0.781	0.938	1.09	1.25	1.41	1.56	1.72	1.88	2.03	2.19	2.34	2.50	2.66	2.81	2.97
1/4	0.833	1.04	1.25	1.46	1.67	1.88	2.08	2.29	2.50	2.71	2.92	3.13	3.33	3.54	3.75	3.96
5/16	1.04	1.30	1.56	1.82	2.08	2.34	2.60	2.86	3.13	3.39	3.65	3.91	4.17	4.43	4.69	4.95
3/8	1.25	1.56	1.88	2.19	2.50	2.81	3.13	3.44	3.75	4.06	4.38	4.69	5.00	5.31	5.63	5.94
7/16	1.46	1.82	2.19	2.55	2.92	3.28	3.65	4.01	4.38	4.74	5.10	5.47	5.83	6.20	6.56	6.93
1/2	1.67	2.08	2.50	2.92	3.33	3.75	4.17	4.58	5.00	5.42	5.83	6.25	6.67	7.08	7.50	7.92
9/16	1.88	2.34	2.81	3.28	3.75	4.22	4.69	5.16	5.63	6.09	6.56	7.03	7.50	7.97	8.44	8.91
5/8	2.08	2.60	3.13	3.65	4.17	4.69	5.21	5.73	6.25	6.77	7.29	7.81	8.33	8.85	9.38	9.90
11/16	2.29	2.86	3.44	4.01	4.58	5.16	5.73	6.30	6.88	7.45	8.02	8.59	9.17	9.74	10.31	10.89
3/4	2.50	3.13	3.75	4.38	5.00	5.63	6.25	6.88	7.50	8.13	8.75	9.38	10.00	10.63	11.25	11.88
13/16	2.71	3.39	4.06	4.74	5.42	6.09	6.77	7.45	8.13	8.80	9.48	10.16	10.83	11.51	12.19	12.86
7/8	2.92	3.65	4.38	5.10	5.83	6.56	7.29	8.02	8.75	9.48	10.21	10.94	11.67	12.40	13.13	13.85
15/16	3.13	3.91	4.69	5.47	6.25	7.03	7.81	8.59	9.38	10.16	10.94	11.72	12.50	13.28	14.06	14.84
1	3.33	4.17	5.00	5.83	6.67	7.50	8.33	9.17	10.00	10.83	11.67	12.50	13.33	14.17	15.00	15.83
1 1/16	3.54	4.43	5.31	6.20	7.08	7.97	8.85	9.74	10.63	11.51	12.40	13.28	14.17	15.05	15.94	16.82
1 1/8	3.75	4.69	5.63	6.56	7.50	8.44	9.38	10.31	11.25	12.19	13.13	14.06	15.00	15.94	16.88	17.81
1 3/16	3.96	4.95	5.94	6.93	7.92	8.91	9.90	10.89	11.88	12.86	13.85	14.84	15.83	16.82	17.81	18.80
1 1/4	4.17	5.21	6.25	7.29	8.33	9.38	10.42	11.46	12.50	13.54	14.58	15.63	16.67	17.71	18.75	19.79
1 5/16	4.37	5.47	6.56	7.66	8.75	9.84	10.94	12.03	13.13	14.22	15.31	16.41	17.50	18.59	19.69	20.78
1 3/8	4.58	5.73	6.88	8.02	9.17	10.31	11.46	12.60	13.75	14.90	16.04	17.19	18.33	19.48	20.63	21.77
1 7/16	4.79	5.99	7.19	8.39	9.58	10.78	11.98	13.18	14.38	15.57	16.77	17.97	19.17	20.36	21.56	22.76
1 1/2	5.00	6.25	7.50	8.75	10.00	11.25	12.50	13.75	15.00	16.25	17.50	18.75	20.00	21.25	22.50	23.75
1 9/16	5.21	6.51	7.81	9.11	10.42	11.72	13.02	14.32	15.63	16.93	18.23	19.53	20.83	22.14	23.44	24.74
1 5/8	5.42	6.77	8.13	9.48	10.83	12.19	13.54	14.90	16.25	17.60	18.96	20.31	21.67	23.02	24.38	25.73
1 11/16	5.63	7.03	8.44	9.84	11.25	12.66	14.06	15.47	16.88	18.28	19.69	21.09	22.50	23.91	25.31	26.72
1 3/4	5.83	7.29	8.75	10.21	11.67	13.13	14.58	16.04	17.50	18.96	20.42	21.88	23.33	24.79	26.25	27.71
1 13/16	6.04	7.55	9.06	10.57	12.08	13.59	15.10	16.61	18.13	19.64	21.15	22.66	24.17	25.68	27.19	28.70
1 7/8	6.25	7.81	9.38	10.94	12.50	14.06	15.63	17.19	18.75	20.31	21.88	23.44	25.00	26.56	28.13	29.69
1 15/16	6.46	8.07	9.69	11.30	12.92	14.53	16.15	17.76	19.38	20.99	22.60	24.22	25.83	27.45	29.06	30.68
2	6.67	8.33	10.00	11.67	13.33	15.00	16.67	18.33	20.00	21.67	23.33	25.00	26.67	28.33	30.00	31.67

Weights of Flat Rolled Iron—*Continued*

Thickness in inches	Widths in Inches: 5	5¼	5½	5¾	6	6¼	6½	6¾	7	7½	8	8½	9	10	11	12
1/16	1.04	1.09	1.15	1.20	1.25	1.30	1.35	1.41	1.46	1.56	1.67	1.77	1.88	2.08	2.29	2.50
1/8	2.08	2.19	2.29	2.40	2.50	2.60	2.71	2.81	2.92	3.13	3.33	3.54	3.75	4.17	4.58	5.00
3/16	3.13	3.28	3.44	3.59	3.75	3.91	4.06	4.22	4.38	4.69	5.00	5.31	5.63	6.25	6.88	7.50
1/4	4.17	4.38	4.58	4.79	5.00	5.21	5.42	5.63	5.83	6.25	6.67	7.08	7.50	8.33	9.17	10.00
5/16	5.21	5.47	5.73	5.99	6.25	6.51	6.77	7.03	7.29	7.81	8.33	8.85	9.38	10.42	11.46	12.50
3/8	6.25	6.56	6.88	7.19	7.50	7.81	8.13	8.44	8.75	9.38	10.00	10.63	11.25	12.50	13.75	15.00
7/16	7.29	7.66	8.02	8.39	8.75	9.11	9.48	9.84	10.21	10.94	11.67	12.40	13.13	14.58	16.04	17.50
1/2	8.33	8.75	9.17	9.58	10.00	10.42	10.83	11.25	11.67	12.50	13.33	14.17	15.00	16.67	18.33	20.00
9/16	9.38	9.84	10.31	10.78	11.25	11.72	12.19	12.66	13.13	14.06	15.00	15.94	16.88	18.75	20.63	22.50
5/8	10.42	10.94	11.46	11.98	12.50	13.02	13.54	14.06	14.58	15.63	16.67	17.71	18.75	20.83	22.92	25.00
11/16	11.46	12.03	12.60	13.18	13.75	14.32	14.90	15.47	16.04	17.19	18.33	19.48	20.63	22.92	25.21	27.50
3/4	12.50	13.13	13.75	14.38	15.00	15.63	16.25	16.88	17.50	18.75	20.00	21.25	22.50	25.00	27.50	30.00
13/16	13.54	14.22	14.90	15.57	16.25	16.93	17.60	18.28	18.96	20.31	21.67	23.02	24.38	27.08	29.79	32.50
7/8	14.58	15.31	16.04	16.77	17.50	18.23	18.96	19.69	20.42	21.88	23.33	24.79	26.25	29.17	32.08	35.00
15/16	15.63	16.41	17.19	17.97	18.75	19.53	20.31	21.09	21.88	23.44	25.00	26.56	28.13	31.25	34.38	37.50
1	16.67	17.50	18.33	19.17	20.00	20.83	21.67	22.50	23.33	25.00	26.67	28.33	30.00	33.33	36.67	40.00
1 1/8	18.75	19.69	20.63	21.56	22.50	23.44	24.38	25.31	26.25	28.13	30.00	31.88	33.75	37.50	41.25	45.00
1 1/4	20.83	21.88	22.92	23.96	25.00	26.04	27.08	28.13	29.17	31.25	33.33	35.42	37.50	41.67	45.83	50.00
1 3/8	22.92	24.06	25.21	26.35	27.50	28.65	29.79	30.94	32.08	34.38	36.67	38.96	41.25	45.83	50.42	55.00
1 1/2	25.00	26.25	27.50	28.75	30.00	31.25	32.50	33.75	35.00	37.50	40.00	42.50	45.00	50.00	55.00	60.00
1 5/8	27.08	28.44	29.79	31.15	32.50	33.85	35.21	36.56	37.92	40.63	43.33	46.04	48.75	54.17	59.58	65.00
1 3/4	29.17	30.63	32.08	33.54	35.00	36.46	37.92	39.38	40.83	43.75	46.67	49.58	52.50	58.33	64.17	70.00
1 7/8	31.25	32.81	34.38	35.94	37.50	39.06	40.63	42.19	43.75	46.88	50.00	53.13	56.25	62.50	68.75	75.00
2	33.33	35.00	36.67	38.33	40.00	41.67	43.33	45.00	46.67	50.00	53.33	56.67	60.00	66.67	73.33	80.00

Other sizes.—Weight of other sizes can easily be obtained from the above table by means of combinations or divisions. Thus, for example,

Weight of 12×1¼ equals weight of 12×1 plus weight of 12×¼ 50.00
Or, twice weight of 12×⅝, as it is twice as thick 50.00
Weight of 6×1 15/16 is midway between weight of 6×1⅞ and 6×2 .... 38.75
Weight of 24×15/16, being twice as wide as 12×15/16, equals 75.00

Weights of Iron and Steel Plate

Pounds per square foot

Thick-ness	Iron—estimated	Steel—estimated	Steel—theoretical	Thick-ness	Iron—estimated	Steel—estimated	Steel—theoretical
1/32	1.35	1.40	1.275	11/16	28.25	29.00	28.05
1/16	2.70	2.75	2.550	3/4	30.75	31.50	30.60
3/32	4.00	4.10	3.825	13/16	33.50	34.00	33.15
1/8	5.40	5.50	5.100	7/8	36.00	36.75	35.70
5/32	6.75	6.90	6.375	15/16	38.50	39.25	38.25
3/16	8.10	8.30	7.650	1	41.00	41.75	40.80
7/32	9.50	9.75	8.925	1 1/16	43.50	44.50	43.35
1/4	10.75	11.00	10.200	1 1/8	46.00	46.75	45.90
9/32	12.00	12.25	11.475	1 3/16	48.50	49.50	48.45
5/16	13.25	13.50	12.750	1 1/4	51.00	52.00	51.00
11/32	14.50	14.75	14.025	1 5/16	53.50	54.50	53.55
3/8	16.00	16.25	15.300	1 3/8	56.00	57.25	56.10
13/32	17.00	17.50	16.575	1 7/16	58.50	60.00	58.65
7/16	18.25	18.75	17.850	1 1/2	61.00	62.50	61.20
15/32	19.50	20.00	19.125	1 5/8	66.25	67.75	66.30
1/2	20.75	21.25	20.400	1 3/4	71.25	72.75	71.40
9/16	23.25	23.75	22.950	1 7/8	76.25	78.00	76.50
5/8	25.75	26.25	25.500	2	81.50	83.25	81.60

Sheets are used in refinery construction, as black sheets for covering wooden tank roofs, manufacture of drums, etc.; as galvanized sheets in flat and corrugated form, for roofing and sheathing purposes; and as tin plates for can manufacture. The tables immediately following show the weights of the sizes most frequently used.

Weights of Black Steel Sheets

U. S. gage	Thick-ness, inches	Pounds per square foot	U. S. gage	Thick-ness, inches	Pounds per square foot	U. S. gage	Thick-ness, inches	Pounds per square foot
10	9/64	5.738	20	3/80	1.53	28	1/64	0.6375
12	7/64	4.462	22	1/32	1.275	29	9/640	0.5737
14	5/64	3.187	24	1/40	1.02	30	1/80	0.51
16	1/16	2.55	26	3/160	0.765			
18	1/20	2.04	27	11/640	0.7012			

WEIGHTS OF STANDARD GALVANIZED SHEETS

(American Sheet & Tin Plate Co.)

Gage	Ounces per square foot	Pounds per square foot	Gage	Ounces per square foot	Pounds per square foot	Gage	Ounces per square foot	Pounds per square foot
8	112.5	7.031	17	38.5	2.406	26	14.5	0.906
9	102.5	6.406	18	34.5	2.156	27	13.5	.844
10	92.5	5.781	19	30.5	1.906	28	12.5	.781
11	82.5	5.156	20	26.5	1.656	29	11.5	.719
12	72.5	4.531	21	24.5	1.531	30	10.5	.656
13	62.5	3.906	22	22.5	1.406	31	9.5	.594
14	52.5	3.281	23	20.5	1.281	32	9.0	.563
15	47.5	2.969	24	18.5	1.156	33	8.5	.531
16	42.5	2.656	25	16.5	1.031	34	8.0	.500

STANDARD WEIGHTS AND GAGES OF TIN PLATE

(American Sheet & Tin Plate Co., Pittsburgh)

Trade term	Nearest wire gage number	Weight per square foot, pound	Weight of box, 14×20 inches, pounds	Trade term	Nearest wire gage number	Weight per square foot, pound	Weight of box, 14×20 inches, pounds
55 lb.	38	0.252	55	IXL	28	0.588	128
60 "	37	.275	60	DC	28	.638	139
65 "	36	.298	65	2X	27	.711	155
70 "	35	.321	70	2XL	27	.679	148
75 "	34	.344	75	3X	26	.803	175
80 "	33	.367	80	3XL	26	.771	168
85 "	32	.390	85	DX	26	.826	180
90 "	31	.413	90	4X	25	.895	195
95 "	31	.436	95	4XL	25	.863	188
100 "	30½	.459	100	D2X	24	.964	210
IC	30	.491	107	D3X	23	1.102	240
118 lb.	29	.542	118	D4X	22	1.239	270
IX	28	.619	135				

Corrugated Sheets—Weight per 100 Square Feet, Pounds
(American Sheet & Tin Plate Co., Pittsburgh, 1914)

Corrugations	⅝ inch		1¼ inches		2 inches		2½ inches,* 26 inches wide	
U. S. std. sheet metal gage	Painted	Galvanized	Painted	Galvanized	Painted	Galvanized	Painted	Galvanized
29	....	81	....	81	....	77	....	77
28	71	88	71	88	68	84	68	84
27	78	95	78	95	75	91	75	91
26	85	102	85	102	82	98	82	98
25	99	116	99	116	95	111	95	111
24	113	130	113	130	109	125	109	125
23	....	....	127	144	122	138	122	138
22	....	....	141	158	136	151	136	151
21	....	....	155	172	149	165	149	165
20	....	....	169	186	163	178	163	178
18	....	....	....	....	216	232	216	232
16	....	....	....	....	270	286	270	286
14	....	....	....	....	....	....	338	353
12	....	....	....	....	....	....	472	488
10	....	....	....	....	....	....	607	623

Corrugations	2½ inches,† 27½ inches wide		3 inches		5 inches	
U. S. std. sheet metal gage	Painted	Galvanized	Painted	Galvanized	Painted	Galvanized
29	....	78	....	77	....	77
28	69	85	68	84	68	84
27	76	92	75	91	75	91
26	83	99	82	98	81	97
25	97	113	95	111	95	111
24	110	126	109	125	108	124
23	124	140	122	138	122	137
22	137	153	136	151	135	151
21	151	167	149	165	148	164
20	165	181	163	178	162	178
18	219	235	216	232	215	231
16	274	290	270	286	269	285
14	342	358	338	353	336	352
12	478	494	472	488	470	486
10	615	631				

* Siding. † Roofing.

Covering width of plates, lapped one corrugation, 24 inches. Standard lengths 5, 6, 7, 8, 9, and 10 feet; maximum length, 12 feet.

Ordinary corrugated sheets should have a lap of 1½ or 2 corrugations side-lap for roofing in order to secure water-tight side seams; if the roof is rather steep 1½ corrugations will answer. Some manufacturers make a special high-edge corrugation on sides of sheets, and thereby are enabled to secure a waterproof side-lap with one corrugation only, thus saving from 6 per cent to 12 per cent of material to cover a given area.

No. 28 gage corrugated iron is generally used for applying to wooden buildings, but for applying to iron framework No. 24 gage or heavier should be adopted.

Galvanizing sheet iron adds about 2½ oz. to its weight per square foot.

Rods in the shape of reinforcing bars, or plain rounds and squares, are used for various purposes in refinery construction. The reader is referred to the various manufacturers of special reinforcing bars for data as to weights, sizes, etc. The following table covers only standard rounds and squares in frequent use.

SQUARE AND ROUND BARS, WEIGHTS AND AREAS

Size, inches	Weight, Pounds per Foot		Area, Square Inches		Size, inches	Weight, Pounds per Foot		Area, Square Inches	
	Square	Round	Square	Round		Square	Round	Square	Round
1/16	0.013	0.010	0.0039	0.0031	1 1/16	3.838	3.015	1.1289	0.8866
1/8	.053	.042	.0156	.0123	1 1/8	4.303	3.380	1.2656	0.9940
3/16	.120	.194	.0352	.0276	1 3/16	4.795	3.766	1.4102	1.1075
1/4	.213	.167	.0625	.0491	1 1/4	5.313	4.172	1.5625	1.2272
5/16	.332	.261	.0977	.0767	1 5/16	5.857	4.600	1.7227	1.3530
3/8	.478	.376	.1406	.1105	1 3/8	6.428	5.049	1.8906	1.4849
7/16	.651	.511	.1914	.1503	1 7/16	7.026	5.518	2.0664	1.6230
1/2	.850	.668	.2500	.1963	1 1/2	7.650	6.008	2.2500	1.7671
9/16	1.076	.845	.3164	.2485	1 9/16	8.301	6.519	2.4414	1.9175
5/8	1.328	1.043	.3906	.3068	1 5/8	8.978	7.051	2.6406	2.0739
11/16	1.607	1.262	.4727	.3712	1 11/16	9.682	7.604	2.8477	2.2365
3/4	1.913	1.502	.5625	.4418	1 3/4	10.413	8.178	3.0625	2.4053
13/16	2.245	1.763	.6602	.5185	1 13/16	11.170	8.773	3.2852	2.5802
7/8	2.603	2.044	.7656	.6013	1 7/8	11.953	9.388	3.5156	2.7612
15/16	2.988	2.347	.8789	.6903	1 15/16	12.763	10.024	3.7539	2.9483
1	3.400	2.670	1.0000	.7854	2	13.600	10.681	4.0000	3.1416

While various structural shapes, from I-beams to Z-bars, are used in refinery construction, detailed statements of their properties, safe loads, etc., are beyond the scope of this volume, the reader being referred to the various booklets of the Carnegie, Cambria, and Lackawanna steel companies for standard shapes, and to that of the Bethlehem Corporation for H-sections. Data on oil and gas line-pipe and well-tubing are given in another chapter of this volume.[1] The tables immediately following cover standard wrought pipe manufactured from skelp, seamless tubing formed from billets; and various items manufactured from rod stock in general refinery use.

[1] See page 687.

STANDARD WROUGHT STEAM, GAS AND WATER PIPE

Table of standard dimensions

Diameter: Nominal Internal, inches	Diameter: External, inches	Diameter: Approximate Internal diameter, inches	Nominal thickness, inches	Circumference: External, inches	Circumference: Internal, inches	Transverse Areas: External, Square inches	Transverse Areas: Internal, Square inches	Transverse Areas: Metal, Square inches	Length of Pipe per Square Foot of: External surface, feet	Length of Pipe per Square Foot of: Internal surface, feet	Length of pipe containing 1 cubic foot, feet	Nominal Weight per Foot: Plain ends	Nominal Weight per Foot: Threaded and coupled	Number of threads per inch of screw
1/8	0.405	0.269	0.068	1.272	0.845	0.129	0.057	0.072	9.431	14.199	2533.775	0.244	0.245	27
1/4	.540	.364	.088	1.696	1.144	.229	.104	.125	7.073	10.493	1383.789	.424	.425	18
3/8	.675	.493	.091	2.121	1.549	.358	.191	.167	5.658	7.747	754.360	.567	.568	18
1/2	.840	.622	.109	2.639	1.954	.554	.304	.250	4.547	6.141	473.906	.850	.852	14
3/4	1.050	.824	.113	3.299	2.589	.866	.533	.333	3.637	4.635	270.034	1.130	1.134	14
1	1.315	1.049	.133	4.131	3.296	1.358	.864	.494	2.904	3.641	166.618	1.678	1.684	11½
1¼	1.660	1.380	.140	5.215	4.335	2.164	1.495	.668	2.301	2.767	96.275	2.272	2.281	11½
1½	1.900	1.610	.145	5.969	5.058	2.835	2.036	.799	2.010	2.372	70.732	2.717	2.731	11½
2	2.375	2.067	.154	7.461	6.494	4.430	3.355	1.075	1.608	1.847	42.913	3.652	3.678	11½
2½	2.875	2.469	.203	9.032	7.757	6.492	4.788	1.704	1.328	1.547	30.077	5.793	5.819	8
3	3.500	3.068	.216	10.996	9.638	9.621	7.393	2.228	1.091	1.245	19.479	7.575	7.616	8
3½	4.000	3.548	.226	12.566	11.146	12.566	9.886	2.680	0.954	1.076	14.565	9.109	9.202	8
4	4.500	4.026	.237	14.137	12.648	15.904	12.730	3.174	.848	0.948	11.312	10.790	10.889	8
4½	5.000	4.506	.247	15.708	14.156	19.635	15.947	3.688	.763	.847	9.030	12.538	12.642	8
5	5.563	5.047	.258	17.477	15.856	24.306	20.006	4.300	.686	.756	7.198	14.617	14.810	8
6	6.625	6.065	.280	20.813	19.054	34.472	28.891	5.581	.576	.629	4.984	18.974	19.185	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.738	6.926	.500	.543	3.717	23.544	23.769	8
8	8.625	8.071	.277	27.096	25.356	58.426	51.161	7.265	.442	.473	2.815	24.696	25.000	8
8	8.625	7.981	.322	27.096	25.073	58.426	50.027	8.399	.442	.478	2.878	28.554	28.809	8
9	9.625	8.941	.342	30.238	28.089	72.760	62.786	9.974	.396	.427	2.294	33.907	34.189	8
10	10.750	10.192	.279	33.772	32.018	90.763	81.585	9.177	.355	.374	1.765	31.201	32.000	8
10	10.750	10.137	.307	33.772	31.843	90.763	80.691	10.072	.355	.376	1.785	34.240	35.000	8
10	10.750	10.020	.365	33.772	31.479	90.763	78.855	11.908	.355	.381	1.826	40.483	41.132	8
11	11.750	11.000	.375	36.914	34.558	108.434	95.033	13.401	.325	.347	1.515	45.557	46.247	8
12	12.750	12.090	.330	40.055	37.982	127.676	114.800	12.876	.299	.315	1.254	43.773	45.000	8
12	12.750	12.000	.375	40.055	37.699	127.676	113.097	14.579	.299	.318	1.273	49.562	50.706	8
13	14.000	13.250	.375	43.982	41.626	153.938	137.886	16.052	.272	.288	1.044	54.568	55.824	8
14	15.000	14.250	.375	47.124	44.768	176.715	159.485	17.230	.254	.268	.903	58.573	60.375	8
15	16.000	15.250	.375	50.265	47.909	201.062	182.654	18.408	.238	.250	.788	62.570	64.500	8

EXTRA STRONG WROUGHT PIPE

Table of standard dimensions

Diameter			Nominal thickness,	Circumference		Transverse Areas			Length of Pipe per Square Foot of		Length of pipe containing 1 cubic foot,	Nominal weight per foot plain ends,
Nominal internal, inches	External, inches	Approximate internal, inches	inches	External, inches	Internal, inches	External, square inches	Internal, square inches	Metal, square inches	External surface, feet	Internal surface, feet	feet	pounds
1/8	0.405	0.215	0.095	1.272	0.675	0.129	0.036	0.093	9.431	17.766	3966.392	0.314
1/4	.540	.302	.119	1.696	.949	.229	.072	.157	7.073	12.648	2010.290	.535
3/8	.675	.423	.126	2.121	1.329	.358	.141	.217	5.658	9.030	1024.689	.738
1/2	.840	.546	.147	2.639	1.715	.554	.234	.320	4.547	6.995	615.018	1.087
3/4	1.050	.742	.154	3.299	2.331	.866	.433	.433	3.637	5.147	333.016	1.473
1	1.315	.957	.179	4.131	3.007	1.358	.719	.639	2.904	3.991	200.193	2.171
1¼	1.660	1.278	.191	5.214	4.015	2.164	1.283	.881	2.301	2.988	112.256	2.996
1½	1.900	1.500	.200	5.969	4.712	2.835	1.767	1.068	2.010	2.546	81.487	3.631
2	2.375	1.939	.218	7.461	6.092	4.430	2.953	1.477	1.608	1.969	48.766	5.022
2½	2.875	2.323	.276	9.032	7.298	6.492	4.238	2.254	1.328	1.644	33.976	7.661
3	3.500	2.900	.300	10.996	9.111	9.621	6.605	3.016	1.091	1.317	21.801	10.252
3½	4.000	3.364	.318	12.566	10.568	12.567	8.888	3.678	.954	1.135	16.202	12.505
4	4.500	3.826	.337	14.137	12.020	15.904	11.497	4.407	.848	.998	12.525	14.983
4½	5.000	4.290	.355	15.708	13.477	19.635	14.455	5.180	.763	.890	9.962	17.611
5	5.563	4.813	.375	17.477	15.120	24.306	18.194	6.112	.686	.793	7.915	20.778
6	6.625	5.761	.432	20.813	18.099	34.472	26.067	8.405	.576	.663	5.524	28.573
7	7.625	6.625	.500	23.955	20.813	45.664	34.472	11.192	.500	.576	4.177	38.048
8	8.625	7.625	.500	27.096	23.955	58.426	45.663	12.763	.442	.500	3.154	43.388
9	9.625	8.625	.500	30.238	27.096	72.760	58.426	14.334	.396	.442	2.464	48.728
10	10.750	9.750	.500	33.772	30.631	90.763	74.662	16.101	.355	.391	1.929	54.735
11	11.750	10.750	.500	36.914	33.772	108.434	90.763	17.671	.325	.355	1.587	60.075
12	12.750	11.750	.500	40.055	36.914	127.676	108.434	19.242	.299	.325	1.328	65.415

Double Extra Strong Wrought Pipe

Table of standard dimensions

Diameter: Nominal internal, inches	Diameter: External, inches	Diameter: Approximate internal, inches	Nominal thickness, inches	Circumference: External, inches	Circumference: Internal, inches	Transverse Areas: External, square inches	Transverse Areas: Internal, square inches	Transverse Areas: Metal, square inches	Length of Pipe per Square Foot of: External surface, feet	Length of Pipe per Square Foot of: Internal surface, feet	Length of pipe containing 1 cubic foot, feet	Nominal weight per foot plain ends, pounds
½	0.840	0.252	0.294	2.639	0.792	0.554	0.050	0.504	4.547	15.157	2887.164	1.714
¾	1.050	.434	.308	3.299	1.363	.866	.148	.718	3.637	8.801	973.404	2.440
1	1.315	.599	.358	4.131	1.882	1.358	.282	1.076	2.904	6.376	510.998	3.658
1¼	1.660	.896	.382	5.215	2.815	2.164	.630	1.534	2.301	4.263	228.379	5.214
1½	1.900	1.100	.400	5.969	3.456	2.835	.950	1.885	2.010	3.472	151.526	6.408
2	2.375	1.503	.436	7.461	4.722	4.430	1.774	2.656	1.609	2.541	81.162	9.029
2½	2.875	1.771	.552	9.032	5.564	6.492	2.464	4.028	1.328	2.156	58.457	13.695
3	3.500	2.300	.600	10.996	7.225	9.621	4.155	5.466	1.091	1.660	34.659	18.583
3½	4.000	2.728	.636	12.566	8.570	12.566	5.845	6.721	0.954	1.400	24.637	22.850
4	4.500	3.152	.674	14.137	9.902	15.904	7.803	8.101	.848	1.211	18.454	27.541
4½	5.000	3.580	.710	15.708	11.247	19.635	10.066	9.569	.763	1.066	14.306	32.530
5	5.563	4.063	.750	17.477	12.764	24.306	12.966	11.340	.686	.940	11.107	38.552
6	6.625	4.897	.864	20.813	15.384	34.472	18.835	15.637	.576	.780	7.646	53.160
7	7.625	5.875	.875	23.955	18.457	45.664	27.109	18.555	.500	.650	5.312	63.079
8	8.625	6.875	.875	27.096	21.598	58.426	37.122	21.304	.442	.555	3.879	72.424

ROUND COLD DRAWN SEAMLESS STEEL TUBING
Weight in pounds per foot

Outside diameter, inches	THICKNESS B. W. G. AND FRACTIONS AND EQUIVALENTS IN DECIMALS OF AN INCH																		
	20	18	16	14	13	12	11	10	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
	0.035	0.049	0.065	0.083	0.095	0.109	0.120	0.134	0.156	0.188	0.219	0.250	0.313	0.375	0.500	0.625	0.750	0.875	1.00
$\frac{1}{2}$	0.17	0.24	0.30	0.37	0.41	0.45	0.49												
$\frac{5}{8}$	.22	.30	.39	.48	.54	.60	.65	0.70											
$\frac{3}{4}$	.27	.37	.47	.59	.66	.75	.81	.88	.99	1.13									
$\frac{7}{8}$	.31	.43	.56	.70	.79	.89	.97	1.06	1.20	1.38	1.53								
1	.36	.50	.65	.81	.92	1.04	1.13	1.24	1.41	1.63	1.82	2.00							
$1\frac{1}{8}$	.41	.56	.74	.92	1.04	1.18	1.29	1.42	1.61	1.88	2.12	2.33							
$1\frac{1}{4}$	.45	.63	.82	1.03	1.17	1.33	1.45	1.60	1.82	2.13	2.41	2.67	3.13	3.50					
$1\frac{3}{8}$	.50	.69	.91	1.14	1.30	1.47	1.61	1.77	2.03	2.38	2.70	3.00	3.54	4.00					
$1\frac{1}{2}$	.55	.76	1.00	1.25	1.42	1.62	1.77	1.95	2.24	2.63	2.99	3.33	3.96	4.50	5.33				
$1\frac{3}{4}$	.....	.....	1.17	1.48	1.68	1.91	2.09	2.31	2.66	3.13	3.57	4.00	4.79	5.50	6.67				
2	.....	.....	1.34	1.70	1.93	2.20	2.41	2.67	3.07	3.63	4.16	4.67	5.63	6.50	8.00	9.17			
$2\frac{1}{4}$	.....	.....	1.52	1.92	2.19	2.49	2.73	3.03	3.49	4.13	4.74	5.33	6.46	7.50	9.34	10.84			
$2\frac{1}{2}$	.....	.....	1.69	2.14	2.44	2.78	3.05	3.39	3.91	4.63	5.32	6.00	7.29	8.50	10.67	12.50			
$2\frac{3}{4}$	.....	.....	1.86	2.36	2.69	3.07	3.37	3.74	4.32	5.13	5.91	6.67	8.13	9.51	12.00	14.17			
3	.....	.....	.....	.....	2.95	3.37	3.69	4.10	4.74	5.63	6.49	7.33	8.96	10.50	13.34	15.84	18.00	19.84	21.34
$3\frac{1}{4}$	.....	.....	.....	.....	3.20	3.66	4.01	4.45	5.16	6.13	7.07	8.00	9.79	11.50	14.67	17.50	20.00	22.17	24.01
$3\frac{1}{2}$	.....	.....	.....	.....	3.45	3.94	4.33	4.82	5.57	6.63	7.66	8.67	10.63	12.50	16.00	19.17	22.00	24.51	26.67
$3\frac{3}{4}$	.....	.....	.....	.....	.....	.....	4.65	5.18	5.99	7.13	8.24	9.34	11.46	13.50	17.34	20.84	24.01	26.84	29.34
4	.....	.....	.....	.....	.....	.....	4.97	5.53	6.41	7.63	8.82	10.00	12.29	14.50	18.67	22.50	26.00	29.17	32.01
$4\frac{1}{4}$	.....	.....	.....	.....	.....	.....	.....	5.89	6.82	8.13	9.41	10.67	13.13	15.50	20.00	24.17	28.01	31.51	34.67
$4\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	6.25	7.24	8.63	9.99	11.34	13.96	16.50	21.34	25.84	30.01	33.84	37.34
$4\frac{3}{4}$	.....	.....	.....	.....	.....	.....	.....	6.61	7.66	9.13	10.58	12.00	14.79	17.51	22.67	27.51	32.01	36.18	40.01
5	.....	.....	.....	.....	.....	.....	.....	6.96	8.07	9.63	11.16	12.67	15.63	18.51	24.00	29.17	34.01	38.51	42.68
$5\frac{1}{2}$	.....	.....	.....	.....	.....	.....	.....	7.67	8.91	10.63	12.32	14.00	17.30	20.51	26.67	32.51	38.01	43.17	48.01

AIR

Properties of air.—Air is a mechanical mixture of the gases, oxygen and nitrogen, with about 1 per cent by volume of argon. Atmospheric air of ordinary purity contains about 0.04 per cent of carbon dioxide. The composition of air is variously given as follows:

	By Volume			By Weight		
	N	O	Ar	N	O	Ar
1	79.3	20.7	......	77	23	......
2	79.09	20.91	......	76.85	23.15	......
3	78.122	20.941	0.937	75.539	23.024	1.437
4	78.06	21	0.94	75.5	23.2	1.3

The weight of pure air at 32° F. and a barometric pressure of 29.92 inches of mercury, or 14.6963 pounds per square inch, or 2116.3 pounds per square foot, is 0.080728 pound per cubic foot. Volume of 1 pound = 12.387 cubic feet. At any other temperature and barometric pressure its weight in pounds per cubic foot is $W=\frac{1.3253\times B}{459.6+T}$, where $B=$ height of the barometer, $T=$ temperature, and $1.3253=$ weight in pounds of 459.6 cubic feet of air at 0° F. and 1 inch barometric pressure. Air expands 1/491.6 of its volume at 32° F. for every increase of 1° F., and its volume varies inversely as the pressure.

Pressure of the Atmosphere per Square Inch and per Square Foot at Various Readings of the Barometer

Rule.—Barometer in inches $\times 0.4916 =$ pressure per square inch; pressure per square inch $\times 144 =$ pressure per square foot.

Barometer	Pressure per square inch	Pressure per square foot	Barometer	Pressure per square inch	Pressure per square foot
Inches	Pounds	Pounds	Inches	Pounds	Pounds
28.00	13.75	1980	29.75	14.61	2104
28.25	13.88	1998	30.00	14.73	2122
28.50	14.00	2016	30.25	14.86	2140
28.75	14.12	2033	30.50	14.98	2157
29.00	14.24	2051	30.75	15.10	2175
29.25	14.37	2069	31.00	15.23	2193
29.50	14.49	2086			

Conversion Table for Air Pressures

	Pounds per square foot	Inches of water	Ounces per square inch	Feet of water	Inches of mercury	Pounds per square inch	Feet of air at 62° F.	$V = \sqrt{2gH}$ feet per second
1 pound per square foot	1	0.19245	1/9	0.01604	0.01414	1/144	13.14	29.1
1 inch water at 62°F.	5.196	1	0.5774	1/12	0.07347	0.036085	68.30	66.3
1 ounce per square inch	9	1.732	1	0.1443	0.1272	1/16	118.3	87.2
1 foot water at 62° F.	62.355	12	6.928	1	0.8816	0.43302	819.6	230
1 inch mercury at 32° F.	70.73	13.612	7.859	1.1343	1	0.49117	929.6	245
1 pound per square inch	144	27.712	16	2.3094	2.036	1	1893	349
1 atmosphere	2116.3	407.27	.....	33.94	29.921	14.6963	27,815	1338
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

The figures in column (8) show the head in feet of air of uniform density to atmospheric pressure and 62° F. corresponding to the pressure in the preceding columns, and those in column (9) the theoretical velocities corresponding to these heads, or the velocities of a jet flowing from a frictionless conical orifice whose flow coefficient is unity.

Moisture in the atmosphere.—Atmospheric air always contains a small quantity of carbonic acid, and a varying quantity of aqueous vapor or moisture. The relative humidity of the air at any time is the percentage of moisture contained in it as compared with the amount it is capable of holding at the same temperature.

The degree of saturation or relative humidity of the air is determined by the use of the dry and wet bulb thermometer. The degree of saturation for a number of different readings of the thermometer is given in the following table, condensed from the Hygrometric Tables of the U. S. Weather Bureau:

Relative Humidity, Per Cent

Dry thermometer, degrees F.	Difference between the Dry and Wet Thermometers, Degrees F.																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	26	28	30
	Relative humidity, saturation being 100. (Barometer = 30 inches.)																										
32	89	79	69	59	49	39	30	20	11	2																	
40	92	83	75	68	60	52	45	37	29	23	15	7	0														
50	93	87	80	74	67	61	55	49	43	38	32	27	21	16	11	5	0										
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1						
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6			
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	12	7	
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	22	17	13
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	28	24	21
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	34	30	26
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	38	34	31
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	44	41	38

Weight of Air per Cubic Foot at Different Pressures and Temperatures

Formula: $W = 0.080728 \times \frac{P}{14.6963} \times \frac{491.6}{T+459.6}$

Temperature		Gage 0	1	2	5	10	20	40	60	80	100	120
Degrees F.	Absolute	$P=$ 14.6963	$P=$ 15.696	$P=$ 16.696	$P=$ 19.696	$P=$ 24.696	$P=$ 34.696	$P=$ 54.696	$P=$ 74.696	$P=$ 94.696	$P=$ 114.696	$P=$ 134.696
0	459.6	0.086349	0.09222	0.09810	0.11573	0.14511	0.20385	0.32137	0.43888	0.55639	0.67391	0.79141
32	491.6	.080728	.08622	.09171	.10819	.13566	.19059	.30045	.41031	.52017	.63004	.73990
42	501.6	.079119	.08450	.08989	.10604	.13295	.18679	.29446	.40213	.50980	.61748	.72515
52	511.6	.077572	.08285	.08813	.10396	.13035	.18314	.28871	.39427	.49984	.60541	.71097
62	521.6	.076085	.08126	.08644	.10197	.12786	.17963	.28317	.38671	.49026	.59380	.69734
70	529.6	.074936	.08004	.08513	.10043	.12592	.17691	.27887	.38087	.48285	.58483	.68681
80	539.6	.073547	.07855	.08356	.09857	.12359	.17364	.27372	.37381	.47390	.57399	.67408
90	549.6	.072209	.07712	.08204	.09678	.12134	.17048	.26874	.36701	.46528	.56355	.66182
100	559.6	.070918	.07574	.08057	.09504	.11937	.16743	.26394	.36045	.45697	.55348	.64999
120	579.6	.068471	.07313	.07779	.09177	.11506	.16165	.25483	.34802	.44120	.53438	.62756
140	599.6	.066187	.07069	.07519	.08871	.11122	.15626	.24633	.33641	.42648	.51656	.60663
160	619.6	.064051	.06841	.07277	.08584	.10763	.15122	.23838	.32555	.41272	.49988	.58705
180	639.6	.062048	.06627	.07049	.08316	.10427	.14649	.23093	.31537	.39981	.48425	.56869
200	659.6	.060167	.06426	.06835	.08064	.10111	.14205	.22393	.30581	.38769	.46957	.55145
250	709.6	.055927	.05973	.06354	.07496	.09398	.13204	.20815	.28426	.36037	.43649	.51259
300	759.6	.052245	.05580	.05936	.07002	.08779	.12335	.19445	.26555	.33665	.40775	.47885
350	809.6	.049019	.05236	.05569	.06570	.08237	.11573	.18244	.24915	.31586	.38257	.44925
400	859.6	.046168	.04931	.05245	.06188	.07758	.10900	.17183	.23466	.29748	.36032	.42314
450	909.6	.043630	.04660	.04957	.05847	.07332	.10301	.16238	.22176	.28113	.34051	.39988
500	959.6	.041357	.04417	.04699	.05543	.06950	.09764	.15392	.21020	.26648	.32277	.37905
550	1009.6	.039309	.04198	.04466	.05268	.06606	.09280	.14630	.19979	.25329	.30678	.36028
600	1059.6	.037454	.04000	.04255	.05020	.06294	.08842	.13939	.19037	.24133	.29230	.34327
650	1109.6	.035766	.03820	.04063	.04793	.06010	.08444	.13311	.18179	.23046	.27913	.32781
700	1159.6	.034224	.03655	.03888	.04587	.05751	.08080	.12737	.17395	.22052	.26710	.31367
800	1259.6	.031507	.03365	.03579	.04223	.05294	.07438	.11726	.16014	.20301	.24589	.28877
900	1359.6	.029190	.03118	.03316	.03912	.04905	.06891	.10864	.14836	.18808	.22781	.26753
1000	1459.6	.027190	.02904	.03089	.03644	.04569	.06419	.10119	.13830	.17519	.21220	.24920

Mixtures of Air and Saturated Vapor

(From Goodenough's Tables)

Temp. ° F.	Pressure of Saturated Vapor		Weight of Saturated Vapor		Volume in Cubic Feet		B.t.u. per pound dry air above 0° F.	Latent heat of vapor, B.t.u.	B.t.u. of 1 pound dry air with vapor to saturate it
	Inches mercury	Pounds per square inch	Per cubic foot	Per pound of dry air	Of 1 pound dry air	Of 1 pound dry air +vapor			
0	0.0375	0.0184	0.0000674	0.000781	11.58	11.59	0.0	0.964	0.964
10	.0628	.0308	.0001103	.001309	11.83	11.86	2.411	1.608	4.019
20	.1027	.0504	.000177	.002144	12.09	12.13	4.823	2.623	7.446
32	.1806	.0887	.000303	.003782	12.39	12.47	7.716	4.058	11.783
35	.2036	.1000	.000340	.004268	12.47	12.55	8.44	4.57	13.02
40	.2478	.1217	.000410	.005202	12.59	12.70	9.65	5.56	15.21
45	.3003	.1475	.000492	.00632	12.72	12.85	10.86	6.73	17.59
50	.3624	.1780	.000588	.00764	12.84	13.00	12.07	8.12	20.19
55	.4356	.2140	.000699	.00920	12.97	13.16	13.28	9.76	23.04
60	.5214	.2561	.000829	.01105	13.10	13.33	14.48	11.69	26.18
65	.6218	.3054	.000979	.01323	13.22	13.50	15.69	13.96	29.65
70	.7386	.3628	.001153	.01578	13.35	13.69	16.90	16.61	33.51
75	.8744	.4295	.001352	.01877	13.48	13.88	18.11	19.71	37.81
80	1.0314	.5066	.001580	.02226	13.60	14.09	19.32	23.31	42.64
85	1.212	.5955	.001841	.02634	13.73	14.31	20.53	27.51	48.04
90	1.421	.6977	.002137	.03109	13.86	14.55	21.74	32.39	54.13
95	1.659	.8148	.002474	.03662	13.98	14.80	22.95	38.06	61.01
100	1.931	.9486	.002855	.04305	14.11	15.08	24.16	44.63	68.79
105	2.241	1.1010	.003285	.0505	14.24	15.39	25.37	52.26	77.63
110	2.594	1.274	.003769	.0593	14.36	15.73	26.58	61.11	87.69
115	2.994	1.470	.004312	.0694	14.49	16.10	27.79	71.40	99.10
120	3.444	1.692	.004920	.0813	14.62	16.52	29.00	83.37	112.37
130	4.523	2.221	.006356	.1114	14.88	17.53	31.42	113.64	145.06
140	5.878	2.887	.008130	.1532	15.13	18.84	33.85	155.37	189.22
150	7.566	3.716	.01030	.2122	15.39	20.60	36.27	214.03	250.3
160	9.649	4.739	.01294	.2987	15.64	23.09	38.69	299.55	338.2
170	12.20	5.990	.01611	.4324	15.90	26.84	41.12	431.2	472.3
180	15.29	7.51	.01991	.6577	16.16	33.04	43.55	651.9	695.5
190	19.01	9.34	.02441	1.0985	16.41	45.00	45.97	1082.3	1128.3
200	23.46	11.53	.02972	2.2953	16.67	77.24	48.40	2247.5	2296

Below 32° F. the pressure of saturated vapor in contact with ice is given. Values in the last column do not include the heat of the liquid. Below 32° F. the heat of sublimation of ice rather than the latent heat of vaporization is used.

WATER

Water boils under atmospheric pressure (14.7 pounds at sea level) at 212° F., passing off as steam. Its greatest density is at 39.1° F., when it weighs 62.425 pounds per cubic foot.

Boiling Point of Water

Temperature in degrees F., barometer in inches of mercury

Inches	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
28	208.7	208.9	209.1	209.2	209.4	209.5	209.7	209.9	210.1	210.3
29	210.5	210.6	210.8	210.9	211.1	211.3	211.4	211.6	211.8	212.0
30	212.1	212.3	212.4	212.6	212.8	212.9	213.1	213.3	213.5	213.6

At 70° F. pure water will boil at 1° less of temperature for an average of about 550 feet of elevation above sea level, up to a height of ½ mile. At the height of 1 mile, 1° of boiling temperature will correspond to about 560 feet of elevation.

Boiling point in degrees F.	Barometer, inches	Altitude above sea level, feet	Boiling point in degrees F.	Barometer, inches	Altitude above sea level, feet	Boiling point in degrees F.	Barometer, inches	Altitude above sea level, feet
184	16.79	15,221	196	21.71	8481	208	27.73	2063
185	17.16	14,649	197	22.17	7932	208.5	28.00	1809
186	17.54	14,075	198	22.64	7381	209	28.29	1539
187	17.93	13,498	199	23.11	6843	209.5	28.56	1290
188	18.32	12,934	200	23.59	6304	210	28.85	1025
189	18.72	12,367	201	24.08	5764	210.5	29.15	754
190	19.13	11,799	202	24.58	5225	211	29.42	512
191	19.54	11,243	203	25.08	4697	211.5	29.71	255
192	19.96	10,685	204	25.59	4169	212	30.0	S.L. = 0
193	20.39	10,127	205	26.11	3642	212.5	30.30	−261
194	20.82	9,579	206	26.64	3115	213	30.59	−511
195	21.26	9,031	207	27.18	2589			

Corrections for Temperature

Mean temp. F. in shade	0	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
Multiply by	0.933	0.954	0.975	0.996	1.016	1.036	1.058	1.079	1.100	1.121	1.142

B. T. U.'s in Water Between 32° and 212° F.

Temperature, F.	Heat-units per pound	Weight, pounds per cubic foot	Temperature, F.	Heat-units per pound	Weight, pounds per cubic foot	Temperature, F.	Heat-units per pound	Weight, pounds per cubic foot	Temperature, F.	Heat-units per pound	Weight, pounds per cubic foot
32°	0.00	62.42	110°	78.00	61.89	145°	113.26	61.28	179°	147.54	60.57
35	3.02	62.42	112	80.00	61.86	146	114.27	61.26	180	148.54	60.55
40	8.06	62.42	113	81.01	61.84	147	115.28	61.24	181	149.55	60.53
45	13.08	62.42	114	82.02	61.83	148	116.29	61.22	182	150.56	60.50
50	18.10	62.41	115	83.02	61.82	149	117.30	61.20	183	151.57	60.48
52	20.11	62.40	116	84.03	61.80	150	118.30	61.18	184	152.58	60.46
54	22.11	62.40	117	85.04	61.78	151	119.31	61.16	185	153.58	60.44
56	24.11	62.39	118	86.05	61.77	152	120.32	61.14	186	154.59	60.41
58	26.12	62.38	119	87.06	61.75	153	121.33	61.12	187	155.60	60.39
60	28.12	62.37	120	88.06	61.74	154	122.34	61.10	188	156.61	60.37
62	30.12	62.36	121	89.07	61.72	155	123.34	61.08	189	157.62	60.34
64	32.12	62.35	122	90.08	61.70	156	124.35	61.06	190	158.62	60.32
66	34.12	62.34	123	91.09	61.68	157	125.36	61.04	191	159.63	60.29
68	36.12	62.33	124	92.10	61.67	158	126.37	61.02	192	160.63	60.27
70	38.11	62.31	125	93.10	61.65	159	127.38	61.00	193	161.64	60.25
72	40.11	62.30	126	94.11	61.63	160	128.38	60.98	194	162.65	60.22
74	42.11	62.28	127	95.12	61.61	161	129.39	60.96	195	163.66	60.20
76	44.11	62.27	128	96.13	61.60	162	130.40	60.94	196	164.66	60.17
78	46.10	62.25	129	97.14	61.58	163	131.41	60.92	197	165.67	60.15
80	48.09	62.23	130	98.14	61.56	164	132.42	60.90	198	166.68	60.12
82	50.08	62.21	131	99.15	61.54	165	133.42	60.87	199	167.69	60.10
84	52.07	62.19	132	100.16	61.52	166	134.43	60.85	200	168.70	60.07
86	54.06	62.17	133	101.17	61.51	167	135.44	60.83	201	169.70	60.05
88	56.05	62.15	134	102.18	61.49	168	136.45	60.81	202	170.71	60.02
90	58.04	62.13	135	103.18	61.47	169	137.46	60.79	203	171.72	60.00
92	60.03	62.11	136	104.19	61.45	170	138.46	60.77	204	172.73	59.97
94	62.02	62.09	137	105.20	61.43	171	139.47	60.75	205	173.74	59.95
96	64.01	62.07	138	106.21	61.41	172	140.48	60.73	206	174.74	59.92
98	66.01	62.05	139	107.22	61.39	173	141.49	60.70	207	175.75	59.89
100	68.01	62.02	140	108.22	61.37	174	142.50	60.68	208	176.76	59.87
102	70.00	62.00	141	109.23	61.36	175	143.50	60.66	209	177.77	59.84
104	72.00	61.97	142	110.24	61.34	176	144.51	60.64	210	178.78	59.82
106	74.00	61.95	143	111.25	61.32	177	145.52	60.62	211	179.78	59.79
108	76.00	61.92	144	112.26	61.30	178	146.53	60.59	212	180.79	59.76

Comparison of Heads of Water in Feet with Pressures in Various Units

One foot of water at 39.1° F. = 62.425 pounds on the square foot
" " " = 0.4335 pound on the square inch
" " " = 0.0295 atmosphere
" " " = 0.8826 inch of mercury at 32°
" " " = 773.3 feet of air at 32° and atmospheric pressure

One pound on the square foot, at 39.1° F.	= 0.01602	foot of water
One pound on the square inch, at 39.1° F.	= 2.307	feet of water
One atmosphere of 29.922 inches of mercury	= 33.9	feet of water
One inch of mercury at 32°	= 1.133	feet of water
One foot of air at 32°, and 1 atmosphere	= 0.001293	foot of water
One foot of average sea-water	= 1.026	feet of pure water
One foot of water at 62° F.	= 62.355	pounds per square foot
One foot of water at 62° F.	= 0.43302	pound per square inch
One inch of water at 62° F. = 0.5774 ounce	= 0.036085	pound per square inch
One pound of water on the square inch at 62° F.	= 2.3094	feet of water
One ounce of water on the square inch at 62° F.	= 1.732	inches of water

Pressure in Pounds per Square Inch for Different Heads of Water

At 62° F. 1 foot head = 0.433 pound per square inch, 0.433 × 144 = 62.352 pounds per cubic foot

Head, feet	0	1	2	3	4	5	6	7	8	9
0	......	0.433	0.866	1.299	1.732	2.165	2.598	3.031	3.464	3.897
10	4.330	4.763	5.196	5.629	6.062	6.495	6.928	7.361	7.794	8.227
20	8.660	9.093	9.526	9.959	10.392	10.825	11.258	11.691	12.124	12.557
30	12.990	13.423	13.856	14.289	14.722	15.155	15.588	16.021	16.454	16.887
40	17.320	17.753	18.186	18.619	19.052	19.485	19.918	20.351	20.784	21.217
50	21.650	22.083	22.516	22.949	23.382	23.815	24.248	24.681	25.114	25.547
60	25.980	26.413	26.846	27.279	27.712	28.145	28.578	29.011	29.444	29.877
70	30.310	30.743	31.176	31.609	32.042	32.475	32.908	33.341	33.774	34.207
80	34.640	35.073	35.506	35.939	36.372	36.805	37.238	37.671	38.104	38.537
90	38.970	39.403	39.836	40.269	40.702	41.135	41.568	42.001	42.436	42.867

Head in Feet of Water, Corresponding to Pressures in Pounds per Square Inch

1 pound per square inch = 2.30947 feet head, 1 atmosphere = 14.7 pounds per square inch = 33.94 feet head

Pressure	0	1	2	3	4	5	6	7	8	9
0	......	2.309	4.619	6.928	9.238	11.547	13.857	16.166	18.476	20.785
10	23.0947	25.404	27.714	30.023	32.333	34.642	36.952	39.261	41.570	43.880
20	46.1894	48.499	50.808	53.118	55.427	57.737	60.046	62.356	64.665	66.975
30	69.2841	71.594	73.903	76.213	78.522	80.831	83.141	85.450	87.760	90.069
40	92.3788	94.688	96.998	99.307	101.62	103.93	106.24	108.55	110.85	113.16
50	115.4735	117.78	120.09	122.40	124.71	127.02	129.33	131.64	133.95	136.26
60	138.5682	140.88	143.19	145.50	147.81	150.12	152.42	154.73	157.04	159.35
70	161.6629	163.97	166.28	168.59	170.90	173.21	175.52	177.83	180.14	182.45
80	184.7576	187.07	189.38	191.69	194.00	196.31	198.61	200.92	203.23	205.54
90	207.8523	210.16	212.47	214.78	217.09	219.40	221.71	224.02	226.33	228.64

STEAM

Table of Properties of Saturated Steam

Pressure in pounds per square inch above vacuum	Temperature in degrees, F.	Total heat in heat units from water at 32°	Heat in liquid from 32° in units	Heat of vaporization, or latent heat in heat units	Density or weight of cubic foot in pounds	Volume of 1 pound in cubic feet	Factor of equivalent evaporation at 212°	Total pressure above vacuum
1	101.99	1113.1	70.0	1043.0	0.00299	334.5	0.9661	1
2	126.27	1120.5	94.4	1026.1	.00576	173.6	.9738	2
3	141.62	1125.1	109.8	1015.3	.00844	118.5	.9786	3
4	153.09	1128.6	121.4	1007.2	.01107	90.33	.9822	4
5	162.34	1131.5	130.7	1000.8	.01366	73.21	.9852	5
6	170.14	1133.8	138.6	995.2	.01622	61.65	.9876	6
7	176.90	1135.9	145.4	990.5	.01874	53.39	.9897	7
8	182.92	1137.7	151.5	986.2	.02125	47.06	.9916	8
9	188.33	1139.4	156.9	982.5	.02374	42.12	.9934	9
10	193.25	1140.9	161.9	979.0	.02621	38.15	.9949	10
15	213.03	1146.9	181.8	965.1	.03826	26.14	1.0003	15
20	227.95	1151.5	196.9	954.6	.05023	19.91	1.0051	20
25	240.04	1155.1	209.1	946.0	.06199	16.13	1.0099	25
30	250.27	1158.3	219.4	938.9	.07360	13.59	1.0129	30
35	259.19	1161.0	228.4	932.6	.08508	11.75	1.0157	35
40	267.13	1163.4	236.4	927.0	.09644	10.37	1.0182	40
45	274.29	1165.6	243.6	922.0	.1077	9.285	1.0205	45
50	280.85	1167.6	250.2	917.4	.1188	8.418	1.0225	50
55	286.89	1169.4	256.3	913.1	.1299	7.698.	1.0245	55
60	292.51	1171.2	261.9	909.3	.1409	7.097	1.0263	60
65	297.77	1172.7	267.2	905.5	.1519	6.583	1.0280	65
70	302.71	1174.3	272.2	902.1	.1628	6.143	1.0295	70
75	307.38	1175.7	276.9	898.8	.1736	5.760	1.0309	75
80	311.80	1177.0	281.4	895.6	.1843	5.426	1.0323	80
85	316.02	1178.3	285.8	892.5	.1951	5.126	1.0337	85
90	320.04	1179.6	290.0	889.6	.2058	4.859	1.0350	90
95	323.89	1180.7	294.0	886.7	.2165	4.619	1.0362	95
100	327.58	1181.9	297.9	884.0	.2271	4.403	1.0374	100
105	331.13	1182.9	301.6	881.3	.2378	4.205	1.0385	105
110	334.56	1184.0	305.2	878.8	.2484	4.026	1.0396	110
115	337.86	1185.0	308.7	876.3	.2589	3.862	1.0406	115
120	341.05	1186.0	312.0	874.0	.2695	3.711	1.0416	120
125	344.13	1186.9	315.2	871.7	.2800	3.571	1.0426	125
130	347.12	1187.8	318.4	869.4	.2904	3.444	1.0435	130
140	352.85	1189.5	324.4	865.1	.3113	3.212	1.0453	140
150	358.26	1191.2	330.0	861.2	.3321	3.011	1.0470	150
160	363.40	1192.8	335.4	857.4	.3530	2.833	1.0486	160
170	368.29	1194.3	340.5	853.8	.3737	2.676	1.0502	170
180	372.97	1195.7	345.4	850.3	.3945	2.535	1.0517	180
190	377.44	1197.1	350.1	847.0	.4153	2.408	1.0531	190
200	381.73	1198.4	354.6	843.8	.4359	2.294	1.0545	200
225	391.79	1201.4	365.1	836.3	.4876	2.051	1.0576	225
250	400.99	1204.2	374.7	829.5	.5393	1.854	1.0605	250
275	409.50	1206.8	383.6	823.2	.5913	1.691	1.0632	275
300	417.42	1209.3	391.9	817.4	.644	1.553	1.0657	300
325	424.82	1211.5	399.6	811.9	.696	1.437	1.0680	325
350	431.90	1213.7	406.9	806.8	.748	1.337	1.0703	350
375	438.40	1215.7	414.2	801.5	.800	1.250	1.0724	375
400	445.15	1217.7	421.4	796.3	.853	1.172	1.0745	400
500	466.57	1224.2	444.3	779.9	1.065	0.939	1.0812	500

The temperature of steam in contact with water depends upon the pressure under which it is generated. At the ordinary atmospheric pressure (14.7 pounds per square inch) its temperature is 212° F. As the pressure is increased, as by the steam being generated in a closed vessel, its temperature, and that of the water in its presence, increases.

Saturated steam is steam of the temperature due to its pressure—not superheated.

Latent heat of steam.—The latent heat, or heat of vaporization, is obtained by subtracting from the total heat at any given temperature the heat of the liquid, or total heat above 32° in water of the same temperature.

The total heat in steam (above 32°) includes three elements:

1st. The heat required to raise the temperature of the water to the temperature of the steam.

2d. The heat required to evaporate the water at that temperature, called internal latent heat.

3d. The latent heat of volume, or the external work done by the steam in making room for itself against the pressure of the superincumbent atmosphere (or surrounding steam if inclosed in a vessel).

The sum of the last two elements is called the latent heat of steam.

Heat Required to Generate 1 Pound of Steam from Water at 32° F.

		Heat-units.
Sensible heat, to raise the water from 32° to 212° = ...		180.0
Latent heat, 1, of the formation of steam at 212° = ...	897.6	
2, of expansion against the atmospheric pressure, 2116.4 pounds per square foot ×26.79 cubic feet = 55,786 foot-pounds ÷ 778 = ...	72.8	
		970.4
Total heat above 32° F...........		1150.4

Properties of Superheated Steam

v = specific volume in cubic feet per pound, h = total heat, from water at 32° F. in B.t.u. per pound, n = entropy, from water at 32°

Pressure absolute, pounds per square inch	Temperature saturated steam		Degrees of Superheat									
			0	20	50	100	150	200	250	300	400	500
20	228.0	v	20.08	20.73	21.69	23.25	24.80	26.33	27.85	29.37	32.39	35.40
		h	1156.2	1165.7	1179.9	1203.5	1227.1	1250.6	1274.1	1297.6	1344.8	1392.2
		n	1.7320	1.7456	1.7652	1.7961	1.8251	1.8524	1.8781	1.9026	1.9479	1.9893
40	267.3	v	10.49	10.83	11.33	12.13	12.93	13.70	14.48	15.25	16.78	18.30
		h	1169.4	1179.3	1194.0	1218.4	1242.4	1266.4	1290.3	1314.1	1361.6	1409.3
		n	1.6761	1.6895	1.7089	1.7392	1.7674	1.7940	1.8189	1.8427	1.8867	1.9271
60	292.7	v	7.17	7.40	7.75	8.30	8.84	9.36	9.89	10.41	11.43	12.45
		h	1177.0	1187.3	1202.6	1227.6	1252.1	1276.4	1300.4	1324.3	1372.2	1420.0
		n	1.6432	1.6568	1.6761	1.7062	1.7342	1.7603	1.7849	1.8081	1.8511	1.8908
80	312.0	v	5.47	5.65	5.92	6.34	6.75	7.17	7.56	7.95	8.72	9.49
		h	1182.3	1193.0	1208.8	1234.3	1259.0	1283.6	1307.8	1331.9	1379.8	1427.9
		n	1.6200	1.6338	1.6532	1.6833	1.7110	1.7368	1.7612	1.7840	1.8265	1.8658
100	327.8	v	4.43	4.58	4.79	5.14	5.47	5.80	6.12	6.44	7.07	7.69
		h	1186.3	1197.5	1213.8	1239.7	1264.7	1289.4	1313.6	1337.8	1385.9	1434.1
		n	1.6020	1.6160	1.6358	1.6658	1.6933	1.7188	1.7428	1.7656	1.8079	1.8468
120	341.3	v	3.73	3.85	4.04	4.33	4.62	4.89	5.17	5.44	5.96	6.48
		h	1189.6	1201.1	1217.9	1244.1	1269.3	1294.1	1318.4	1342.7	1391.0	1439.4
		n	1.5873	1.6016	1.6216	1.6517	1.6789	1.7041	1.7280	1.7505	1.7924	1.831
140	353.1	v	3.22	3.32	3.49	3.75	4.00	4.24	4.48	4.71	5.16	5.61
		h	1192.2	1204.3	1221.4	1248.0	1273.3	1298.2	1322.6	1346.9	1395.4	1443.8
		n	1.5747	1.5894	1.6096	1.6395	1.6666	1.6916	1.7152	1.7376	1.7792	1.8177
160	363.6	v	2.83	2.93	3.07	3.30	3.53	3.74	3.95	4.15	4.56	4.95
		h	1194.5	1207.0	1224.5	1251.3	1276.8	1301.7	1326.2	1350.6	1399.3	1447.9
		n	1.5639	1.5789	1.5993	1.6292	1.6561	1.6810	1.7043	1.7266	1.7680	1.8063
180	373.1	v	2.53	2.62	2.75	2.96	3.16	3.35	3.54	3.72	4.09	4.44
		h	1196.4	1209.4	1227.2	1254.3	1279.9	1304.8	1329.5	1353.9	1402.7	1451.4
		n	1.5543	1.5697	1.5904	1.6201	1.6468	1.6716	1.6948	1.7169	1.7581	1.7962

PROPERTIES OF SUPERHEATED STEAM—*Continued*

Pressure absolute, pounds per square inch	Temperature saturated steam		Degrees of Superheat									
			0	20	50	100	150	200	250	300	400	500
200	381.9	v	2.29	2.37	2.49	2.68	2.86	3.04	3.21	3.38	3.71	4.03
		h	1198.1	1211.6	1229.8	1257.1	1282.6	1307.7	1332.4	1357.0	1405.9	1454.7
		n	1.5456	1.5614	1.5823	1.6120	1.6385	1.6632	1.6862	1.7082	1.7493	1.7872
220	389.9	v	2.09	2.16	2.28	2.45	2.62	2.78	2.94	3.10	3.40	3.69
		h	1199.6	1213.6	1232.2	1259.6	1285.2	1310.3	1335.1	1359.8	1408.8	1457.7
		n	1.5379	1.5541	1.5753	1.6049	1.6312	1.6558	1.6787	1.7005	1.7415	1.7792
240	397.4	v	1.92	1.99	2.09	2.26	2.42	2.57	2.71	2.85	3.13	3.40
		h	1200.9	1215.4	1234.3	1261.9	1287.6	1312.8	1337.6	1362.3	1411.5	1460.5
		n	1.5309	1.5476	1.5690	1.5985	1.6246	1.6492	1.6720	1.6937	1.7344	1.7721
260	404.5	v	1.78	1.84	1.94	2.10	2.24	2.39	2.52	2.65	2.91	3.16
		h	1202.1	1217.1	1236.4	1264.1	1289.9	1315.1	1340.0	1364.7	1414.0	1463.2
		n	1.5244	1.5416	1.5631	1.5926	1.6186	1.6430	1.6658	1.6874	1.7280	1.7655
280	411.2	v	1.66	1.72	1.81	1.95	2.09	2.22	2.35	2.48	2.72	2.95
		h	1203.1	1218.7	1238.4	1266.2	1291.9	1317.2	1342.2	1367.0	1416.4	1465.7
		n	1.5185	1.5362	1.5580	1.5873	1.6133	1.6375	1.6603	1.6818	1.7223	1.7597
300	417.5	v	1.55	1.60	1.69	1.83	1.96	2.09	2.21	2.33	2.55	2.77
		h	1204.1	1220.2	1240.3	1268.2	1294.0	1319.3	1344.3	1369.2	1418.6	1468.0
		n	1.5129	1.5310	1.5530	1.5824	1.6082	1.6323	1.6550	1.6765	1.7168	1.7541
350	431.9	v	1.33	1.38	1.46	1.58	1.70	1.81	1.92	2.02	2.22	2.41
		h	1206.1	1223.9	1244.6	1272.7	1298.7	1324.1	1349.3	1374.3	1424.0	1473.7
		n	1.5002	1.5199	1.5423	1.5715	1.5971	1.6210	1.6436	1.6650	1.7052	1.7422
400	444.8	v	1.17	1.21	1.28	1.40	1.50	1.60	1.70	1.79	1.97	2.14
		h	1207.7	1227.2	1248.6	1276.9	1303.0	1328.6	1353.9	1379.1	1429.0	1478.9
		n	1.4894	1.5107	1.5336	1.5625	1.5880	1.6117	1.6342	1.6554	1.6955	1.7323
450	456.5	v	1.04	1.08	1.14	1.25	1.35	1.44	1.53	1.61	1.77	1.93
		h	1209	1231	1252	1281	1307	1333	1358	1383	1434	1484
		n	1.479	1.502	1.526	1.554	1.580	1.603	1.626	1.647	1.687	1.723
500	467.3	v	0.93	0.97	1.03	1.13	1.22	1.31	1.39	1.47	1.62	1.76
		h	1210	1233	1256	1285	1311	1337	1362	1388	1438	1489
		n	1.470	1.496	1.519	1.548	1.573	1.597	1.619	1.640	1.679	1.715

FLOW OF STEAM IN PIPES, FOR A DROP OF 1 POUND PER 1000 FEET LENGTH, POUNDS PER MINUTE

(p_1 = initial pressure, by gage, pounds per square inch; w = density, pounds per cubic foot.)

Nominal diameter of pipe, inches	Actual internal diameter, d	28-in. vac. $w = .002851$	$p_1 = 0.3$ $w = .03732$	$p_1 = 2.3$ $w = .04277$	$p_1 = 5.3$ $w = .04980$	$p_1 = 10.3$ $w = .0614$	$p_1 = 50.3$ $w = .1503$	$p_1 = 100.3$ $w = .2577$	$p_1 = 150.3$ $w = .3633$	$p_1 = 200.3$ $w = .468$	$p_1 = 250.3$ $w = .571$
½	0.622	0.017	0.062	0.067	0.072	0.080	0.123	0.163	0.195	0.222	0.245
¾	0.824	.039	.141	.151	.163	.181	.283	.380	.442	.500	.552
1	1.049	.079	.284	.305	.328	.365	.571	.747	.887	1.007	1.112
1¼	1.380	.173	.626	.670	.723	.803	1.256	1.645	1.953	2.217	2.448
1½	1.610	.269	.973	1.041	1.123	1.247	1.952	2.556	3.034	3.444	3.804
2	2.067	.545	1.970	2.110	2.276	2.527	3.954	5.177	6.147	6.977	7.706
2½	2.469	.898	3.248	3.478	3.751	4.166	6.517	8.534	10.13	11.50	12.70
3	3.068	1.642	5.943	6.364	6.865	7.622	11.93	15.62	18.54	21.04	23.24
3½	3.548	2.450	8.878	9.508	10.26	11.40	17.81	23.32	27.71	31.43	34.74
4	4.026	3.471	12.56	13.45	14.51	16.11	25.20	33.00	39.18	44.47	49.12
4½	4.506	4.712	17.08	18.27	19.73	21.91	34.28	44.88	53.29	60.48	66.81
5	5.047	6.425	23.25	24.90	26.85	29.82	46.65	61.09	72.53	82.32	90.93
6	6.065	10.51	38.02	40.72	43.92	48.77	76.30	99.91	118.6	134.6	148.7
7	7.023	15.60	56.45	60.46	65.21	72.41	113.3	148.3	176.1	199.9	220.8
8	7.981	22.00	79.60	85.23	91.97	102.0	159.7	209.2	248.4	281.9	311.2
9	8.941	29.63	107.1	114.7	123.8	137.5	215.1	281.6	334.4	379.6	418.8
10	10.020	39.98	144.6	154.9	167.0	185.5	290.3	380.1	451.3	512.2	565.8
11	11.000	51.16	185.1	198.2	213.8	237.4	371.5	486.4	577.5	655.5	723.2
12	12.000	64.26	232.5	249.0	268.6	298.2	466.6	611.0	725.5	823.4	909.5
13	13.250	83.20	301.0	322.3	347.7	386.1	604.1	791.0	939.2	1066.	1177.
14	14.250	100.6	363.9	389.6	420.3	466.7	730.2	956.1	1135	1288	1423
15	15.250	119.9	433.9	464.6	501.2	556.5	870.7	1140	1354	1538	1697
17 O.D.	16.214	140.6	508.9	544.9	587.9	652.7	1021	1337	1588	1802	1990
18 O.D.	17.182	163.4	591.3	634.7	683.1	758.5	1187	1554	1845	2094	2313
20 O.D.	19.182	217.1	785.7	841.4	907.6	1008	1577	2065	2451	2782	3074
22 O.D.	21.250	282.6	1022	1095	1181	1311	2052	2687	3190	3621	3999
24 O.D.	23.250	356.5	1290	1381	1490	1654	2588	3389	4024	4567	5045

To reduce actual evaporation to the standard at and from 212° F.—The quantity of heat required for evaporating 1 pound of water under atmospheric pressure at and from 212° F. is 965.66 units.

$$w=\frac{W(H-h)}{965.66}.$$

W = actual evaporation in pounds of water per unit of time;
w = standard evaporation at and from 212° F.:
H = units of heat per pound of steam actually evaporated and to be found in the steam table;
h = units of heat per pound of the feed water to be found in the water table.

The actual evaporation multiplied by the tabular number is the standard evaporation. The table on page 801 is computed from the above formula.

Expansion of steam pipes.—The linear expansion and contraction of a pipe carrying steam, with the rise and fall of the temperature, must be taken care of by the use of some form of expansion joint or bend. To find the total expansion due to an increase in temperature, multiply the length of pipe in inches by the coefficient of expansion and by the temperature range.

The expansion for each 100 feet of length for different degrees Fahrenheit is given in the table on page 802, which is taken from the *Practical Engineer*, January, 1911. The expansion for any length between two temperatures is found by taking the difference in length at these temperatures, dividing by 100 and multiplying by the length of the pipe in feet.

SAFETY VALVES

Calculation of weight, etc., for lever safety valves

Let W = weight of ball at end of lever;
w = weight of lever itself;
V = weight of valve and spindle, all in pounds;
L = distance between fulcrum and center of ball;
l = distance between fulcrum and center of valve;
g = distance between fulcrum and center of gravity of lever, all in inches;
A = area of valve, in square inches;
P = pressure of steam, in pounds per square inch, at which valve will open.

Then

$$PA\times l=W\times L+w\times g+V\times l;$$

whence

$$P=(WL+wg+Vl)\div Al;\ W=(PAl-wg-Vl)\div L;\ L=(PAl-wg-Vl)\div W.$$

Example.—Diameter of valve, 4 inches; distance from fulcrum to center of ball, 36 inches; to center of valve, 4 inches; to center of gravity of lever, 15½ inches; weight of valve and spindle, 3 pounds; weight of lever, 7 pounds; required the weight of ball to make the blowing-off pressure 80 pounds per square inch; area of 4-inch valve = 12.566 square inches. Then

$$W=\frac{PAl-wg-Vl}{L}=\frac{80\times 12.566\times 4-7\times 15\tfrac{1}{2}-3\times 4}{36}=108.4 \text{ pounds}.$$

Factors of Evaporation

Temper- of feed water degrees F.	Steam Pressure by Gage															
	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
32	1.214	1.216	1.220	1.222	1.225	1.227	1.229	1.231	1.232	1.234	1.236	1.237	1.239	1.240	1.241	1.243
40	1.206	1.209	1.212	1.214	1.216	1.219	1.220	1.222	1.224	1.226	1.227	1.229	1.230	1.232	1.233	1.234
50	1.195	1.197	1.201	1.204	1.206	1.208	1.210	1.212	1.214	1.215	1.217	1.218	1.220	1.221	1.223	1.224
60	1.185	1.188	1.191	1.193	1.196	1.198	1.200	1.202	1.203	1.205	1.207	1.208	1.210	1.211	1.212	1.214
65	1.180	1.183	1.186	1.189	1.191	1.193	1.195	1.197	1.199	1.200	1.202	1.203	1.204	1.206	1.207	1.208
70	1.175	1.178	1.180	1.183	1.185	1.187	1.189	1.191	1.193	1.194	1.196	1.197	1.199	1.200	1.202	1.203
80	1.164	1.167	1.170	1.173	1.175	1.177	1.179	1.181	1.183	1.184	1.186	1.187	1.189	1.190	1.192	1.193
90	1.154	1.157	1.160	1.162	1.165	1.167	1.169	1.170	1.172	1.174	1.176	1.177	1.179	1.180	1.181	1.183
100	1.144	1.147	1.150	1.152	1.154	1.156	1.158	1.160	1.162	1.164	1.165	1.167	1.168	1.170	1.171	1.172
110	1.133	1.136	1.139	1.142	1.144	1.146	1.148	1.150	1.152	1.153	1.155	1.156	1.158	1.159	1.160	1.162
120	1.123	1.126	1.129	1.131	1.133	1.136	1.138	1.140	1.141	1.143	1.145	1.146	1.147	1.149	1.150	1.151
130	1.113	1.116	1.118	1.121	1.123	1.125	1.127	1.129	1.130	1.132	1.134	1.136	1.137	1.138	1.140	1.141
140	1.102	1.105	1.108	1.110	1.113	1.115	1.117	1.119	1.120	1.122	1.124	1.125	1.127	1.128	1.129	1.131
150	1.091	1.095	1.098	1.100	1.102	1.104	1.106	1.108	1.110	1.111	1.113	1.115	1.116	1.118	1.119	1.120
160	1.081	1.084	1.087	1.090	1.092	1.094	1.096	1.098	1.100	1.101	1.103	1.104	1.106	1.107	1.108	1.110
170	1.070	1.074	1.077	1.079	1.081	1.083	1.085	1.087	1.089	1.091	1.092	1.094	1.095	1.097	1.098	1.099
180	1.060	1.063	1.066	1.069	1.071	1.073	1.075	1.077	1.079	1.080	1.082	1.083	1.085	1.086	1.088	1.089
190	1.050	1.053	1.056	1.058	1.060	1.063	1.065	1.066	1.068	1.070	1.071	1.073	1.074	1.076	1.077	1.078
200	1.039	1.043	1.045	1.048	1.050	1.052	1.054	1.056	1.058	1.059	1.061	1.063	1.064	1.065	1.067	1.068
210	1.029	1.032	1.035	1.037	1.040	1.042	1.044	1.046	1.047	1.049	1.051	1.052	1.053	1.055	1.056	1.057
212	1.027	1.030	1.033	1.035	1.037	1.040	1.042	1.044	1.045	1.047	1.049	1.050	1.052	1.053	1.055	1.056

HEAT

TEMPERATURE CON

By ALBERT

−459.4 to 0

C.		F.
−273	**−459.4**	
−268	**−450**	
−262	**−440**	
−257	**−430**	
−251	**−420**	
−246	**−410**	
−240	**−400**	
−234	**−390**	
−229	**−380**	
−223	**−370**	
−218	**−360**	
−212	**−350**	
−207	**−340**	
−201	**−330**	
−196	**−320**	
−190	**−310**	
−184	**−300**	
−179	**−290**	
−173	**−280**	
−169	**−273**	−459.4
−168	**−270**	−454
−162	**−260**	−436
−157	**−250**	−418
−151	**−240**	−400
−146	**−230**	−382
−140	**−220**	−364
−134	**−210**	−346
−129	**−200**	−328
−123	**−190**	−310
−118	**−180**	−292
−112	**−170**	−274
−107	**−160**	−256
−101	**−150**	−238
− 95.6	**−140**	−220
− 90.0	**−130**	−202
− 84.4	**−120**	−184
− 78.9	**−110**	−166
− 73.3	**−100**	−148
− 67.8	**− 90**	−130
− 62.2	**− 80**	−112
− 56.7	**− 70**	− 94
− 51.1	**− 60**	− 76
− 45.6	**− 50**	− 58
− 40.0	**− 40**	− 40
− 34.4	**− 30**	− 22
− 28.9	**− 20**	− 4
− 23.3	**− 10**	14
− 17.8	**0**	32

0 to 100

C.		F.	C.		F.
−17.8	**0**	32	10.0	**50**	122.0
−17.2	**1**	33.8	10.6	**51**	123.8
−16.7	**2**	35.6	11.1	**52**	125.6
−16.1	**3**	37.4	11.7	**53**	127.4
−15.6	**4**	39.2	12.2	**54**	129.2
−15.0	**5**	41.0	12.8	**55**	131.0
−14.4	**6**	42.8	13.3	**56**	132.8
−13.9	**7**	44.6	13.9	**57**	134.6
−13.3	**8**	46.4	14.4	**58**	136.4
−12.8	**9**	48.2	15.0	**59**	138.2
−12.2	**10**	50.0	15.6	**60**	140.0
−11.7	**11**	51.8	16.1	**61**	141.8
−11.1	**12**	53.6	16.7	**62**	143.6
−10.6	**13**	55.4	17.2	**63**	145.4
−10.0	**14**	57.2	17.8	**64**	147.2
− 9.44	**15**	59.0	18.3	**65**	149.0
− 8.89	**16**	60.8	18.9	**66**	150.8
− 8.33	**17**	62.6	19.4	**67**	152.6
− 7.78	**18**	64.4	20.0	**68**	154.4
− 7.22	**19**	66.2	20.6	**69**	156.2
− 6.67	**20**	68.0	21.1	**70**	158.0
− 6.11	**21**	69.8	21.7	**71**	159.8
− 5.56	**22**	71.6	22.2	**72**	161.6
− 5.00	**23**	73.4	22.8	**73**	163.4
− 4.44	**24**	75.2	23.3	**74**	165.2
− 3.89	**25**	77.0	23.9	**75**	167.0
− 3.33	**26**	78.8	24.4	**76**	168.8
− 2.78	**27**	80.6	25.0	**77**	170.6
− 2.22	**28**	82.4	25.6	**78**	172.4
− 1.67	**29**	84.2	26.1	**79**	174.2
− 1.11	**30**	86.0	26.7	**80**	176.0
− 0.56	**31**	87.8	27.2	**81**	177.8
0	**32**	89.6	27.8	**82**	179.6
0.56	**33**	91.4	28.3	**83**	181.4
1.11	**34**	93.2	28.9	**84**	183.2
1.67	**35**	95.0	29.4	**85**	185.0
2.22	**36**	96.8	30.0	**86**	186.8
2.78	**37**	98.6	30.6	**87**	188.6
3.33	**38**	100.4	31.1	**88**	190.4
3.89	**39**	102.2	31.7	**89**	192.2
4.44	**40**	104.0	32.2	**90**	194.0
5.00	**41**	105.8	32.8	**91**	195.8
5.56	**42**	107.6	33.3	**92**	197.6
6.11	**43**	109.4	33.9	**93**	199.4
6.67	**44**	1 1.2	34.4	**94**	201.2
7.22	**45**	113.0	35.0	**95**	203.0
7.78	**46**	114.8	35.6	**96**	204.8
8.33	**47**	116.6	36.1	**97**	206.6
8.89	**48**	118.4	36.7	**98**	208.4
9.44	**49**	120.2	37.2	**99**	210.2
			37.8	**100**	212.0

100 to

C.		F.
38	**100**	212
43	**110**	230
49	**120**	248
54	**130**	266
60	**140**	284
66	**150**	302
71	**160**	320
77	**170**	338
82	**180**	356
88	**190**	374
93	**200**	392
99	**210**	410
100	**212**	413
104	**220**	428
110	**230**	446
116	**240**	464
121	**250**	482
127	**260**	500
132	**270**	518
138	**280**	536
143	**290**	554
149	**300**	572
154	**310**	590
160	**320**	608
166	**330**	626
171	**340**	644
177	**350**	662
182	**360**	680
188	**370**	698
193	**380**	716
199	**390**	734
204	**400**	752
210	**410**	770
216	**420**	788
221	**430**	806
227	**440**	824
232	**450**	842
238	**460**	860
243	**470**	878
249	**480**	896
254	**490**	914

NOTE.—The numbers in bold-face type refer to the temperature either in degrees Centigrade or scale. If converting from Fahrenheit degrees to Centigrade degrees the equivalent temperature will be Centigrade to degrees Fahrenheit, the answer will be found in the column on the right. These tables engineers, Cambridge, Mass. Copyright, 1920. Published by permission.

HEAT—*Continued*

VERSION TABLES

SAUVEUR

1000			1000 to 2000						2000 to 3000					
C.		F.	C.		F.	C.		F.	C.		F.	C.		F.
260	**500**	932	538	**1000**	1832	816	**1500**	2732	1093	**2000**	3732	1371	**2500**	4532
266	**510**	950	543	**1010**	1850	821	**1510**	2750	1099	**2010**	3650	1377	**2510**	4550
271	**520**	968	549	**1020**	1868	827	**1520**	2768	1104	**2020**	3668	1382	**2520**	4568
277	**530**	986	554	**1030**	1886	832	**1530**	2786	1110	**2030**	3686	1388	**2530**	4586
282	**540**	1004	560	**1040**	1904	838	**1540**	2804	1116	**2040**	3704	1393	**2540**	4604
288	**550**	1022	566	**1050**	1922	843	**1550**	2822	1121	**2050**	3722	1399	**2550**	4622
293	**560**	1040	571	**1060**	1940	849	**1560**	2840	1127	**2060**	3740	1404	**2560**	4640
299	**570**	1058	577	**1070**	1958	854	**1570**	2858	1132	**2070**	3758	1410	**2570**	4658
304	**580**	1076	582	**1080**	1976	860	**1580**	2876	1138	**2080**	3776	1416	**2580**	4676
310	**590**	1094	588	**1090**	1994	866	**1590**	2894	1143	**2090**	3794	1421	**2590**	4694
316	**600**	1112	593	**1100**	2012	871	**1600**	2912	1149	**2100**	3812	1427	**2600**	4712
321	**610**	1130	599	**1110**	2030	877	**1610**	2930	1154	**2110**	3830	1432	**2610**	4730
327	**620**	1148	604	**1120**	2048	882	**1620**	2948	1160	**2120**	3848	1438	**2620**	4748
332	**630**	1166	610	**1130**	2066	888	**1630**	2966	1166	**2130**	3866	1443	**2630**	4766
338	**640**	1184	616	**1140**	2084	893	**1640**	2984	1171	**2140**	3884	1449	**2640**	4784
343	**650**	1202	621	**1150**	2102	899	**1650**	3002	1177	**2150**	3902	1454	**2650**	4802
349	**660**	1220	627	**1160**	2120	904	**1660**	3020	1182	**2160**	3920	1460	**2660**	4820
354	**670**	1238	632	**1170**	2138	910	**1670**	3038	1188	**2170**	3938	1466	**2670**	4838
360	**680**	1256	638	**1180**	2156	916	**1680**	3056	1193	**2180**	3956	1471	**2680**	4856
366	**690**	1274	643	**1190**	2174	921	**1690**	3074	1199	**2190**	3974	1477	**2690**	4874
371	**700**	1292	649	**1200**	2192	927	**1700**	3092	1204	**2200**	3992	1482	**2700**	4892
377	**710**	1310	654	**1210**	2210	932	**1710**	3110	1210	**2210**	4010	1488	**2710**	4910
382	**720**	1328	660	**1220**	2228	938	**1720**	3128	1216	**2220**	4028	1493	**2720**	4928
388	**730**	1346	666	**1230**	2246	943	**1730**	3146	1221	**2230**	4046	1499	**2730**	4946
393	**740**	1364	671	**1240**	2264	949	**1740**	3164	1227	**2240**	4064	1504	**2740**	4964
399	**750**	1382	677	**1250**	2282	954	**1750**	3182	1232	**2250**	4082	1510	**2750**	4982
404	**760**	1400	682	**1260**	2300	960	**1760**	3200	1238	**2260**	4100	1516	**2760**	5000
410	**770**	1418	688	**1270**	2318	966	**1770**	3218	1243	**2270**	4118	1521	**2770**	5018
416	**780**	1436	693	**1280**	2336	971	**1780**	3236	1249	**2280**	4136	1527	**2780**	5036
421	**790**	1454	699	**1290**	2354	977	**1790**	3254	1254	**2290**	4154	1532	**2790**	5054
427	**800**	1472	704	**1300**	2372	982	**1500**	3272	1260	**2300**	4172	1538	**2800**	5072
432	**810**	1490	710	**1310**	2390	988	**1810**	3290	1266	**2310**	4190	1543	**2810**	5090
438	**820**	1508	716	**1320**	2408	993	**1820**	3308	1271	**2320**	4208	1549	**2820**	5108
443	**830**	1526	721	**1330**	2426	999	**1830**	3326	1277	**2330**	4226	1554	**2830**	5126
449	**840**	1544	727	**1340**	2444	1004	**1840**	3344	1282	**2340**	4244	1560	**2840**	5144
454	**850**	1562	732	**1350**	2462	1010	**1850**	3362	1288	**2350**	4262	1566	**2850**	5162
460	**860**	1580	738	**1360**	2480	1016	**1860**	3380	1293	**2360**	4280	1571	**2860**	5180
466	**870**	1598	743	**1370**	2498	1021	**1870**	3398	1299	**2370**	4298	1577	**2870**	5198
471	**880**	1616	749	**1380**	2516	1027	**1880**	3416	1304	**2380**	4316	1582	**2880**	5216
477	**890**	1634	754	**1390**	2534	1032	**1890**	3434	1310	**2390**	4334	1588	**2890**	5234
482	**900**	1652	760	**1400**	2552	1038	**1900**	3452	1316	**2400**	4352	1593	**2900**	5252
488	**910**	1670	766	**1410**	2570	1043	**1910**	3470	1321	**2410**	4370	1599	**2910**	5270
493	**920**	1688	771	**1420**	2588	1049	**1920**	3488	1327	**2420**	4388	1604	**2920**	5288
499	**930**	1706	777	**1430**	2606	1054	**1930**	3506	1332	**2430**	4406	1610	**2930**	5306
504	**940**	1724	782	**1440**	2624	1060	**1940**	3524	1338	**2440**	4424	1616	**2940**	5324
510	**950**	1742	788	**1450**	2642	1066	**1950**	3542	1343	**2450**	4442	1621	**2950**	5342
516	**960**	1760	793	**1460**	2660	1071	**1960**	3650	1349	**2460**	4460	1627	**2960**	5360
521	**970**	1778	799	**1470**	2678	1077	**1970**	3578	1354	**2470**	4478	1632	**2970**	5378
527	**980**	1796	804	**1480**	2696	1082	**1980**	3596	1360	**2480**	4496	1638	**2980**	5396
532	**990**	1814	810	**1490**	2714	1088	**1990**	3614	1366	**2490**	4514	1643	**2990**	5414
538	**1000**	1832				1093	**2000**	3632				1649	**3000**	5432

Fahrenheit which it is desired to convert into the other found in the left column, while if converting from degrees are a revision of those by Sauveur and Boylston, metallurgical

INTERPOLATION FACTORS

C.		F.	C.		F.
0.56	**1**	1.8	3.33	**6**	10.8
1.11	**2**	3.6	3.89	**7**	12.6
1.67	**3**	5.4	4.44	**8**	14.4
2.22	**4**	7.2	5.00	**9**	16.2
2.78	**5**	9.0	5.56	**10**	18.0

Expansion of Pipes

(Increase in inches per 100 feet)

Temperature, degrees F.	Cast iron	Wrought iron	Steel	Brass and copper
0	0.00	0.00	0.00	0.00
50	0.36	0.40	0.38	0.57
100	0.72	0.79	0.76	1.14
125	0.88	0.97	0.92	1.40
150	1.10	1.21	1.15	1.75
175	1.28	1.41	1.34	2.04
200	1.50	1.65	1.57	2.38
225	1.70	1.87	1.78	2.70
250	1.90	2.09	1.99	3.02
275	2.15	2.36	2.26	3.42
300	2.35	2.58	2.47	3 74
325	2.60	2.86	2.73	4 13
350	2.80	3.08	2.94	4.45
375	3.15	3.46	3.31	5.01
400	3.30	3.63	3.46	5.24
425	3.68	4.05	3.86	5.85
450	3.89	4.28	4.08	6.18
475	4.20	4.62	4.41	6.68
500	4.45	4.90	4.67	7.06
525	4.75	5.22	4.99	7.55
550	5.05	5.55	5.30	8.03
575	5.36	5.90	5.63	8.52
600	5.70	6.26	5.98	9.06
625	6.05	6.65	6.35	9.62
650	6.40	7.05	6.71	10.18
675	6.78	7.46	7.12	10.78
700	7.15	7.86	7.50	11.37
725	7.58	8.33	7.96	12.06
750	7.96	8.75	8.36	12.66
775	8.42	9.26	8.84	13.38
800	8.87	9.76	9.31	14.10

Interconversion Tables for Units of Volume, Weight and Energy

To Convert from	Multiply by														
	To cu. in.	To cu. ft.	To cu. yd.	To fl. oz.	To pint	To quart	To gallon	To grain	To oz. Troy	To oz.avdp.	To lb.Troy	To lb. avdp.	To cc. or g.	To liter or kg.	To cu. m.
Cubic inches	1.00000	$0.0_{3}5787$	$0.0_{4}2143$	0.554112	0.034623	0.017316	0.004329	252.891	0.526857	0.578037	0.043905	0.036127	16.3871	0.016387	$0.0_{4}1639$
Cubic feet	1728.00	1.00000	0.037037	957.505	59.8442	29.9221	7.48052	436,996	910.408	998.848	75.8674	62.4280	28,316.9	28.3169	0.028317
Cubic yards	46,656.0	27.0000	1.00000	25,852.6	1615.79	807.896	201.974	$117{,}990_{3}$	24,581.0	26,968.9	2048.42	1685.56	764,556	764.556	0.764556
Fluid ounces	1.80469	0.001044	$0.0_{4}3868$	1.00000	0.062500	0.031250	0.007813	456.390	0.950813	1.04318	0.079234	0.065199	29.5736	0.029573	$0.0_{4}2957$
Pint	28.8750	0.016710	$0.0_{3}6189$	16.0000	1.00000	0.500000	0.125000	7302.23	15.2130	16.6908	1.26775	1.04318	473.177	0.473177	$0.0_{4}4732$
Quart	57.7500	0.033420	0.001238	32.0000	2.00000	1.00000	0.250000	1460.45	30.4260	33.3816	2.53550	2.08635	946.354	0.946354	$0.0_{3}9463$
Gallon	231.000	0.133681	0.004951	128.000	8.00000	4.00000	1.00000	58,417.9	121.704	133.527	10.1420	8.34541	3785.42	3.78542	0.003785
Grain	0.003954	$0.0_{5}2288$	$0.0_{7}8475$	0.002191	$0.0_{3}1369$	$0.0_{4}6850$	$0.0_{4}1712$	1.000000	0.002083	0.002286	$0.0_{3}1736$	$0.0_{3}1428$	0.064799	$0.0_{4}6479$	$0.0_{7}6479$
Ounces troy	1.89805	0.001098	$0.0_{4}4068$	1.05173	0.065733	0.032867	0.008217	480.000	1.00000	1.09714	0.083333	0.068571	31.1035	0.031104	$0.0_{4}3110$
Ounces avdp.	1.72999	0.001001	$0.0_{4}3708$	0.958608	0.059913	0.029957	0.007489	437.500	0.911457	1.00000	0.075955	0.062500	28.3495	0.028350	$0.0_{4}2835$
Pounds troy	22.7766	0.013181	$0.0_{3}4882$	12.6208	0.788800	0.394400	0.098600	5760.00	12.0000	13.1657	1.00000	0.822857	373.242	0.373242	$0.0_{3}3732$
Pounds avdp.	27.6799	0.016018	$0.0_{3}5933$	15.3378	0.958611	0.479306	0.119826	7000.00	14.5833	16.0000	1.21528	1.00000	453.593	0.453593	$0.0_{3}4536$
C.c. or gram	0.061024	$0.0_{4}3531$	$0.0_{5}1308$	0.033814	0.002113	0.001057	$0.0_{3}2642$	15.4323	0.032151	0.035274	0.002679	0.002205	1.00000	0.001000	0.000001
Liter or kg.	61.0237	0.035315	0.001308	33.8140	2.11337	1.05669	0.264172	15,432.3	32.1507	35.2739	2.67923	2.20462	1000.00	1.00000	0.001000
Cubic meters	61,023.7	35.3146	1.30795	33,814.0	2113.37	1056.69	264.172	$154{,}320_{3}$	32,150.7	35,273.9	2679.23	2204.62	1,000,000	1000.00	1.00000

Note.—The small subnumeral following a zero indicates that the zero is to be taken that number of times; thus, $0.0_{3}1428$ is equivalent to 0.0001428.

Values used in constructing table
1 inch = 2.540001 cm.
∴ 1 cu. in. = 16.387083 c.c. = 16.387083 g. H_2O at 4° C. = 39° F.

1 lb. avdp. = 453.5926 g.
∴ 1 gal. = 8.34541 lb.
∴ 1 lb. avdp. = 27.679886 cu. in. H_2O at 4° C.

1 lb. avdp. = 7000 grains
∴ 1 gallon = 58417.87 grains
231 cu. in. = 1 gallon = 3785.4162 g.

To Convert from	Multiply by										
	B.t.u.	P.c.u.	Calories	Ft.-lbs.	Ft.-tons	Kg.m.	H.P.-hrs.	Kw.-hrs.	Joules	Lbs. C.	Lbs. H_2O
B.t.u.	1.00000	0.555556	0.251996	778.000	0.389001	107.563	$0.0_{3}3929$	$0.0_{3}2931$	1055.20	$0.0_{4}6876$	0.001031
Pound-centigrade unit	1.80000	1.00000	45.3593	1400.40	0.700202	193.613	$0.0_{3}7072$	$0.0_{3}5276$	1899.36	$0.0_{3}1238$	0.001855
Calories	3.96832	2.20462	1.00000	3091.36	1.54368	426.844	0.001559	0.001163	4187.37	$0.0_{3}2729$	0.004089
Foot-pounds	0.001285	$0.0_{3}7141$	$0.0_{3}3239$	1.00000	0.000500	0.138255	$0.0_{6}5050$	$0.0_{6}3767$	1.35625	$0.0_{7}8840$	$0.0_{5}1325$
Foot-tons	2.57069	1.42816	0.647804	2000.00	1.00000	276.511	0.001010	$0.0_{3}7535$	2712.59	$0.0_{3}1768$	0.002649
Kilogram meters	0.009297	0.005165	0.002343	7.23301	0.003617	1.00000	$0.0_{5}3653$	$0.0_{5}2725$	9.81009	$0.0_{6}6394$	$0.0_{5}9580$
Horse-power hours	2544.99	0.141388	641.327	1,980,000	990.004	273,747	1.00000	0.746000	2,685,473	0.175044	2.62261
Kilowatt hours	3411.57	1895.32	859.702	2,654,200	1327.10	366,959	1.34041	1.00000	3,599,889	0.234648	3.51562
Joules	$0.0_{3}9477$	$0.0_{3}5265$	$0.0_{3}2388$	0.737311	$0.0_{3}3687$	0.101937	$0.0_{6}3724$	$0.0_{6}2778$	1.00000	$0.0_{7}6518$	$0.0_{6}9766$
Pounds carbon	14,544.0	8080.00	3665.03	$113{,}150_{3}$	5657.63	1,564,396	5.71434	4.26285	$153{,}470_{3}$	1.00000	14.9876
Pounds H_2O	970.400	539.111	244.537	754,971	377.487	104,379	.381270	0.284424	1,023,966	0.066744	1.00000

"P.c.u." refers to the "pound-centigrade unit." The ton used is 2000 pounds. "Lbs. C." refers to pounds of carbon oxidized, 100 per cent efficiency, equivalent to the corresponding number of heat-units. "Lbs. H_2O" refers to pounds of water evaporated at 100° C. = 212° F. at 100 per cent efficiency.

(Prepared by the chemical department of the Dupont Co. and published in Chemical and Metallurgical Engineering.)

When volume and weight interconversions are given, water is the medium which the calculations are based upon. By the introduction of specific gravity factors the medium can be changed, giving the weight of any volume of any material, etc.

FUSION POINTS OF SEGER CONES

Symbol or cone No.	Melting Point Degrees C.	Melting Point Degrees F.	Symbol or cone No.	Melting Point Degrees C.	Melting Point Degrees F.	Symbol or cone No.	Melting Point Degrees C.	Melting Point Degrees F.
HECHT SERIES			04	1070	1958	13	1390	2534
022	590	1094	03	1090	1994	14	1410	2570
021	620	1148	02	1110	2030	15	1430	2606
020	650	1202	01	1130	2066	16	1450	2642
019	680	1256	SEGER SERIES			17	1470	2678
018	710	1310	1	1150	2102	18	1490	2714
017	740	1364	2	1170	2138	19	1510	2750
016	770	1418	3	1190	2174	20	1530	2786
015	800	1472	4	1210	2210	HIGH TEMP. SERIES		
012½	875	1607	5	1230	2246			
CREMER SERIES			6	1250	2282	26	Lowest grade for No. 2 Refractories	
010	950	1742	7	1270	2318	30	Lowest grade for No. 1 Refractories	
09	970	1778	8	1290	2354	32	Good quality No. 1 Firebrick	
08	990	1814	9	1310	2390	34	Excellent quality No. 1 Firebrick	
07	1010	1850	10	1330	2426	36	Melting point pure kaolin	
06	1030	1886	11	1350	2462	38	Melting point good quality bauxite	
05	1050	1922	12	1370	2498	42	Melting point pure alumina	

The German cones can be obtained in the United States through Eimer & Amend, New York, and other chemical supply houses. In 1896, Prof. Edw. Orton, Jr., of the Ohio State University, Columbus, Ohio, began their manufacture in America. The American cones agree with the German cones in all respects, and have come into general use in America. They are not sold through dealers, but must be obtained direct from the maker.

High temperatures judged by color.—The temperature of a body can be approximately judged by the experienced eye, unaided. A table constructed in 1836 by M. Pouillet, and generally quoted in the text-books, gives the colors and their corresponding temperatures, but is now replaced by the tables of H. M. Howe and of Maunsel White and F. W. Taylor (*Trans, A. S. M. E.*, 1899), which are given at the top of the opposite page.

Skilled observers may vary 100° F. or more in their estimation of relatively low temperatures by color, and beyond 2200° F. it is practically impossible to make estimations with any certainty whatever. (Bulletin No. 2, Bureau of Standards, 1905.)

In confirmation of the above paragraph we have the second table on page 805, in a booklet published by the Halcomb Steel Co., 1908.

Different substances heated to the same temperature give out the same color tints. Objects which emit the same tint and intensity of light cannot be ditinguished from each other, no matter how different their texture, surface, or shape may be. When the temperature at all parts of a furnace at a low yellow heat is the same, different objects inside

Howe	° C.	° F.
Lowest red visible in dark	470	878
Lowest red visible in daylight	475	887
Dull red	550 to 625	1022 to 1157
Full cherry	700	1292
Light red	850	1562
Full yellow	950 to 1000	1742 to 1832
Light yellow	1050	1922
White	1150	2102

White and Taylor	° C.	° F.
Dark blood-red, black-red	....	990
Dark red, blood-red, low red	556	1050
Dark cherry-red	635	1175
Medium cherry-red	....	1250
Cherry, full red	746	1375
Light cherry, light red *	843	1550
Orange, free scaling heat	899	1650
Light orange	941	1725
Yellow	996	1825
Light yellow	1079	1975
White	1205	2200

* Heat at which scale forms and adheres on iron and steel, i. e., does not fall away from the piece when allowed to cool in air.

the furnace (firebrick, sand, platinum, iron) become absolutely invisible. (H. M. Howe.)

° C.	° F.	Colors	° C.	° F.	Colors
400	752	Red, visible in the dark	1000	1832	Bright cherry-red
474	885	Red, visible in the twilight	1100	2012	Orange-red
525	975	Red, visible in the daylight	1200	2192	Orange-yellow
581	1077	Red, visible in the sunlight	1300	2372	Yellow-white
700	1292	Dark red	1400	2552	White welding heat
800	1472	Dull cherry-red	1500	2732	Brilliant white
900	1652	Cherry-red	1600	2912	Dazzling white (bluish white)

A bright bar of iron, slowly heated in contact with air, assumes the following tints at the corresponding temperatures (Claudel):

	° C.	° F.		° C.	° F.
Yellow at	225	437	Indigo at	288	550
Orange at	243	473	Blue at	293	559
Red at	265	509	Green at	332	630
Violet at	277	531	"Oxide-gray"	400	752

The Halcomb Steel Co. (1908) gives the following heats and temper colors of steel;

° C.	° F.	Colors	° C.	° F.	Colors
221.1	430	Very pale yellow	265.6	510	Spotted red-brown
226.7	440	Light yellow	271.1	520	Brown-purple
232.2	450	Pale straw-yellow	276.7	530	Light purple
237.8	460	Straw-yellow	282.2	540	Full purple
243.3	470	Deep straw-yellow	287.8	550	Dark purple
248.9	480	Dark yellow	293.3	560	Full blue
254.4	490	Yellow-brown	298.9	570	Dark blue
260.0	500	Brown-yellow	315.6	600	Very dark blue

Boiling Point at Atmospheric Pressure

14.7 pounds per square inch

Ether, sulphuric	94° F.	Saturated brine	226° F.
Carbon bisulphide	118	Nitric acid	248
Chloroform	140	Oil of turpentine	315
Bromine	145	Aniline	363
Aqua ammonia, sp. gr. 0.95	146	Naphthalene	424
Wood spirit	150	Phosphorus	554
Alcohol	173	Sulphuric acid	590
Benzine	176	Linseed oil	597
Water	212	Mercury	675
Average sea water	213.2	Sulphur	832

The boiling points of liquids increase as the pressure increases.

Melting Points of Various Substances

The following figures are given by Clark (on the authority of Pouillet, Claudel and Wilson), except those marked *, which are given by Prof. Roberts-Austen, and those marked †, which are given by Dr. J. A. Harker. These last are probably the most reliable figures:

	° F.		° F.
Sulphurous acid	−148	Cadmium	442
Carbonic acid	−108	Bismuth	504 to 507
Mercury	−39, − 38†	Lead	618*, 620†
Bromine	+ 9.5	Zinc	779*, 786†
Turpentine	14	Antimony	1150, 1169†
Hyponitric acid	16	Aluminum	1157*, 1214†
Ice	32	Magnesium	1200
Nitroglycerin	45	NaCl, common salt	1472†
Tallow	92	Calcium	Full red heat
Phosphorus	112	Bronze	1692
Acetic acid	113	Silver	1733*, 1751†
Stearine	109 to 120	Potassium sulphate	1859*, 1958†
Spermaceti	120	Gold	1913*, 1947†
Margaric acid	131 to 140	Copper	1929*, 1943†
Potassium	136 to 144	Nickel	2600†

	°F
Beeswax	142 to 154
Stearic acid	158
Sodium	194 to 208
Iodine	225
Sulphur	239
Alloy, 1½ tin, 1 lead	334, 367†
Tin	446, 449†
Cast iron, white	1922, 2075†
Cast iron, gray	2012 to 2786, 2228*
Steel	2372 to 2532*
Steel, hard	2570*; mild, 2687
Wrought iron	2732 to 2912, 2737*
Palladium	2732*
Platinum	3227*, 3110†

Cobalt and manganese are fusible in the highest heat of a forge. Tungsten and chromium are not fusible in forge, but soften and agglomerate. Platinum and iridium are fusible only before the oxyhydrogen blowpipe, or in an electrical furnace. For melting point of fusible alloys see alloys. Boiling and freezing points of air and other gases, etc., are given below.

INTERESTING TEMPERATURES

	Degrees F.	Degrees C.
Absolute zero	− 459.4	− 273
Hydrogen boils	− 423	− 253
Nitrogen boils	− 321	− 196
Liquid air (oxygen boils)	− 297.4	− 183
Alcohol freezes	− 179.68	− 117.6
Carbon dioxide (sublimation in inert liquid)	− 109.3	− 78.5 *
Mercury freezes	− 37.97	− 38.87*
Ammonia boils	− 37.3	− 38.5
Water freezes	+ 32	0.0 *
Ether boils	94	34.6
Alcohol boils	173.12	78.4
Water boils	212	100 *
Naphthalene boils	423.73	217.96*
Tin melts	449.4	231.9 *
Glycerin boils	554	290
Benzophenone boils	582.6	305.9 *
Lead melts	621.3	327.4 *
Mercury boils	675.05	357.25*
Zinc melts	786.9	419.4 *
Sulphur boils	832.3	444.6 *
Antimony melts	1166	630 *
Aluminum melts	1217.7	658.7 *
Salt (NaCl) solidifies	1473.8	801 *
Silver melts	1761	960.5 *
Gold melts	1945.5	1063 *
Copper melts	1981.5	1083 *
Nickel melts	2646	1452 *
Iron melts	2786	1530 *
Platinum melts	3191	1755 *
Tungsten melts	5430	3000 *
Carbon melts	about 6500	3600

Barometric pressure, 760 mm.

* Bureau of Standards Circular No. 35, Second Edition.

QUANTITATIVE MEASUREMENT OF HEAT

Unit of heat.—The British thermal unit, or heat unit (B.t.u.), is the quantity of heat required to raise the temperature of 1 pound of pure water from 62° to 63° F. (Peabody), or $\frac{1}{180}$ of the heat required to raise the temperature of 1 pound of water from 32° to 212° F. (Marks and Davis, see Steam, p. 867).

The French thermal unit, or *calorie*, is the quantity of heat required to raise the temperature of 1 kilogram of pure water from 15° to 16° C.

1 French calorie = 3.968 British thermal units; 1 B.t.u. = 0.252 calorie. The "pound calorie" is sometimes used by English writers; it is the quantity of heat required to raise the temperature of 1 pound of water 1° C. 1 pound calorie = $\frac{9}{5}$ B.t.u. = 0.4536 calorie. The heat of combustion of carbon to CO_2 is said to be 8080 calories. This figure is used either for French calories or for pound calories, as it is the number of pounds of water that can be raised 1° C. by the complete combustion of 1 pound of carbon, or the number of kilograms of water that can be raised 1° C. by the combustion of 1 kilogram of carbon, assuming in each case that all the heat generated is transferred to the water.

The mechanical equivalent of heat is the number of foot-pounds of mechanical energy equivalent to one British thermal unit, heat and mechanical energy being mutually convertible. Joule's experiments, 1843–50, gave the figure 772, which is known as Joule's eqiuvalent. More recent experiments by Professor Rowland (1880) and others give higher figures; 778 is generally accepted, but 777.6 is probably more nearly correct. (Goodenough Properties of Steam and Ammonia. 1915.)

One heat-unit is equivalent to 778 foot-pounds of energy. One foot-pound = $\frac{1}{778}$ = 0.0012852 heat-unit. One horse-power = 33,000 foot-pounds per minute = 2545 heat-units per hour = 42.416 + per minute = 0.70694 per second. One pound carbon burned to CO_2 = 14,600 heat-units. One pound C per h.p. per hour = 2545 ÷ 14,600 = 17.43 per cent efficiency.

In calculations of the heating value of mixed fuels the value for carbon is commonly taken at 14,600 B.t.u., and that of hydrogen at 62,000. Taking the heating value of C burned to CO_2 at 14,600, and that of C to CO at 4450, the difference, 10,150 B.t.u. is the heat lost by the imperfect combustion of each pound of C burned to CO instead of to CO_2. If the CO formed by this imperfect combustion is afterwards burned to CO_2 the lost heat is regained.

In burning 1 pound of hydrogen with 8 pounds of oxygen to form 9 pounds of water, the units of heat evolved are 62,000; but if the resulting product is not cooled to the initial temperature of the gases, part of the heat is rendered latent in the steam. The total heat of 1 pound of steam at 212° F. is 1150.0 heat units above that of water at 32° and 9 × 1150 = 10,350 heat units, which deducted from 62,000 gives 51,650 as the heat evolved by the combustion of 1 pound of hydrogen and 8 pounds of oxygen at 32° F. to form steam at 212° F.

Some writers subtract from the total heating value of hydrogen only the latent heat of the 9 pounds of steam, or 9 × 970.4 = 8734 B.t.u., leaving as the "low" heating value 53,266 B.t.u.

The use of heating values of hydrogen "burned to steam," in computations relating to combustion of fuel, is inconvenient, since it necessitates a statement of the conditions upon which the figures are based: and it is, moreover, misleading, if not inaccurate, since hydrogen in fuel is not often burned in pure oxygen, but in air; the temperature of the gases before burning is not often the assumed standard temperature, and the products of combustion are not often discharged at 212°. In steam-boiler practice the chimney gases are usually discharged above 300°; but if economizers are used, and the water supplied to them is cold, the gases may be cooled to below 212°, in which case the steam in the gases is condensed and its latent heat of evaporation is utilized. If there

is any need at all of using figures of the "available" heating value of hydrogen, or its heating value when "burned to steam," the fact that the gas is burned in air and not in pure oxygen should be taken into consideration. The resulting figures will then be much lower than those above given, and they will vary with different conditions. (Kent, Steam Boiler Economy, page 23, 1915.)

HEAT OF COMBUSTION OF VARIOUS SUBSTANCES IN OXYGEN

	Heat Units		Authority
	C.	F.	
Hydrogen to liquid water at 0° C.	34,462	62,032	Favre and Silbermann
	33,808	60,854	Andrews
	34,342	61,816	Thomsen
Hydrogen to steam at 100° C.	28,732	51,717	Favre and Silbermann
Carbon (wood charcoal) to carbonic acid, CO_2; ordinary temperatures	8,080	14,544	Favre and Silbermann
	7,900	14,220	Andrews
	8,137	14,647	Berthelot
Carbon (diamond) to CO_2	7,859	14,146	Berthelot
Carbon (black diamond) to CO_2	7,861	14,150	Berthelot
Carbon (graphite) to CO_2	7,901	14,222	Berthelot
Carbon to carbonic oxide, CO	2,473	4,451	Favre and Silbermann
Carbonic oxide to CO_2 per unit of CO	2,403	4,325	Favre and Silbermann
	2,431	4,376	Andrews
	2,385	4,293	Thomsen
CO to CO_2 per unit of $C = 2\frac{1}{3} \times 2403$	5,607	10,093	Favre and Silbermann
Marsh gas, methane, CH_4, to water and CO_2	13,120	23,616	Thomsen
	13,108	23,594	Andrews
	13,063	23,513	Favre and Silbermann
Olefiant gas, ethylene, C_2H_4, to water and CO_2	11,858	21,344	Favre and Silbermann
	11,942	21,496	Andrews
	11,957	21,523	Thomsen
Benzol gas, C_6H_6, to water and CO_2	10,102	18,184	Thomsen
	9,915	17,847	Favre and Silbermann
Sulphur to sulphur dioxide, SO_2	2,250	4,050	N. W. Lord

Suppose that 1 pound of H is burned in twice the quantity of air required for complete combustion, or $2 \times (8\text{ O} + 26.56\text{ N}) = 69.12$ pounds air supplied at 62° F., and that the products of combustion escape at 562° F. The heat lost in the products of combustion will be

	B.t.u.
9 pounds water heated from 62° to 212°	1,352
Latent heat of 9 pounds H_2O at 212°, 9×969.7	8,727
Superheated steam, 9 pounds $\times (562° - 212°) \times 0.48$ (specific heat)	1,512
Nitrogen, $26.56 \times (562° - 62°) \times 0.2438$	3,238
Excess air, $34.56 \times (562° - 62°) \times 0.2375$	4,104
Total	18,933

which subtracted from 62,000 gives 43,067 B.t.u. as the net available heating value under the conditions named.

Heating value of compound or mixed fuels.—The heating value of a solid compound or mixed fuel is the sum of its elementary constituents, and is calculated as follows by Dulong's formula:

$$\text{B.t.u.} = \frac{1}{100}\left[14{,}600\ \text{C} + 62{,}000\left(\text{H} - \frac{\text{O}}{8}\right) + 4500\ \text{S}\right];$$

in which C, H, O, and S are respectively the percentages of the several elements. The term $\text{H} - \frac{1}{8}\,\text{O}$ is called the "available" or "disposable" hydrogen, or that which is not combined with oxygen in the fuel. For all the common varieties of coal, cannel coal and some lignites excepted, the formula is accurate within the limits of error of chemical analyses and calorimetric determinations.

Specific Heat

Thermal capacity.—The thermal capacity of a body between two temperatures T_0 and T_1 is the quantity of heat required to raise the temperature from T_0 to T_1. The ratio of the heat required to raise the temperature of a certain weight of a given substance one degree to that required to raise the temperature of the same weight of water from 62° to 63° F. is commonly called the *specific heat* of the substance. Some writers object to the term as embodying an inaccurate use of the words "specific" and "heat." A more correct name would be "coefficient of thermal capacity."

Determination of specific heat.—*Mixture method.*—The body whose specific heat is to be determined is raised to a known temperature, and is then immersed in a mass of liquid of which the weight, specific heat, and temperature are known. When the body and the liquid have attained the same temperature, this is carefully ascertained.

Now the quantity of heat lost by the body is the same as the quantity of heat absorbed by the liquid.

Let c, w, and t be the specific heat, weight, and temperature of the hot body, and c', w', and t' those of the liquid. Let T be the temperature the mixture assumes. Then, by the definition of specific heat,

$$c \times w \times (t - T) = \text{heat-units lost by the hot body,}$$

and

$$c' \times w' \times (T - t') = \text{heat-units gained by the cold liquid.}$$

If there is no heat lost by radiation or conduction, these must be equal, and

$$cw(t - T) = c'w'(T - t') \quad \text{or} \quad c = \frac{c'w'(T - t')}{w(t - T)}.$$

Electrical Method.—This method is believed to be more accurate in many cases than the mixture method. It consists in measuring the quantity of current in watts required to heat a unit weight of a substance one degree in one minute, and translating the result into heat-units. 1 Watt = 0.0569 B.t.u. per minute.

Specific Heats of Various Substances

Gases

	Constant pressure	Constant volume
Air	0.23751	0.16847
Oxygen	0.21751	0.15507
Hydrogen	3.40900	2.41226
Nitrogen	0.24380	0.17273
Superheated steam	0.4805	0.346
Carbonic acid	0.217	0.171
Olefiant gas, C_2H_4 (ethylene)	0.404	0.332
Carbonic oxide	0.2479	0.1758
Ammonia	0.508	0.299
Ether	0.4797	0.3411
Alcohol	0.4534	0.399
Acetic acid	0.4125	......
Chloroform	0.1567	....

Solids

Antimony	0.0508
Copper	0.0951
Gold	0.0324
Wrought iron	0.1138
Glass	0.1937
Cast iron	0.1298
Lead	0.0314
Platinum	0.0324
Silver	0.0570
Tin	0.0562
Steel (soft)	0.1165
Steel (hard)	0.1175
Zinc	0.0956
Brass	0.0939
Ice	0.5040
Sulphur	0.2026
Charcoal	0.2410
Alumina	0.1970
Phosphorus	0.1887

Other Solids

Brickwork and masonry, about	0.20
Marble	0.210
Chalk	0.215
Quicklime	0.217
Magnesian limestone	0.217
Silica	0.191
Corundum	0.198
Stones generally	0.2 to 0.22
Coal	0.20 to 0.241
Coke	0.203
Graphite	0.202
Sulphate of lime	0.197
Magnesia	0.222
Soda	0.231
Quartz	0.188
River sand	0.195

Woods

When oven dried, 20 varieties of wood showed specific heat nearly the same for all, average 0.327. (U. S. Forest Service, 1911.)

Liquids

Water	1.0000	Mercury	0.0333
Lead (melted)	0.0402	Alcohol (absolute)	0.7000
Sulphur (melted)	0.2340	Fusel oil	0.5640
Bismuth (melted)	0.0308	Benzine	0.4500
Tin (melted)	0.0637	Ether	0.5034
Sulphuric acid	0.3350		
Alcohol, density 0.793	0.622	Olive oil	0.310
Sulphuric acid, density 1.87	0.335	Benzine	0.393
Sulphuric acid, density 1.30	0.661	Turpentine, density 0.872	0.472
Hydrochloric acid	0.600	Bromine	1.111

Expansion by Heat

In the centigrade scale the coefficient of expansion of air per degree is 0.003665 = 1/273; that is, the pressure being constant, the volume of a perfect gas increases 1/273 of its volume at 0° C. for every increase in temperature of 1° C. In Fahrenheit units it increases 1/491.6 = 0.002034 of its volume at 32° F. for every increase of 1° F.

Expansion of Gases by Heat from 32° to 212° F. (Regnault)

	Increase in volume, pressure constant. Volume at 32° F. = 1.0, for		Increase in pressure, volume constant. Pressure at 32° F. = 1.0, for	
	100° C.	1° F.	100° C.	1° F.
Hydrogen	0.3661	0.002034	0.3667	0.002037
Atmospheric air	0.3670	0.002039	0.3665	0.002036
Nitrogen	0.3670	0.002039	0.3668	0.002039
Carbon monoxide	0.3669	0.002038	0.3667	0.002037
Carbon dioxide	0.3710	0.002061	0.3688	0.002039
Sulphur dioxide	0.3903	0.002168	0.3845	0.002136

If the volume is kept constant, the pressure varies directly as the absolute temperature.

Expansion of Liquids from 32° to 212° F.

Apparent expansion in glass (Clark). Volume at 212°, volume at 32° being 1

Water	1.0466	Nitric acid	1.11
Water saturated with salt	1.05	Olive and linseed oils	1.08
Mercury	1.0182	Turpentine and ether	1.07
Alcohol	1.11	Hydrochloric and sulphuric acids	1.06

Linear Expansion of Solids at Ordinary Temperatures
Clark *

	For 1° F. Length = 1	For 1° C. Length = 1	Expansion from 32° to 212° F.	According to other authorities
Aluminum, drawn	0.00001360	0.00002450	0.002450	
Aluminum, cast	0.00001234	0.00002221	0.002221	
Antimony, crystals	0.00000627	0.00001129	0.001129	0.001083
Brass, cast	0.00000957	0.00001722	0.001722	0.001868
Brass, plate	0.00001052	0.00001894	0.001894	
Brick	0.00000306	0.00000550	0.000550	
Brick, fire	0.00000300	0.00000540	0.005400	
Bronze (copper, 17; tin, 2½; zinc, 1)	0.00000986	0.00001774	0.001774	
Bismuth	0.00000975	0.00001755	0.001755	0.001392
Cement, Portland (mixed), pure	0.00000594	0.00001070	0.001070	
Concrete (cement-mortar and pebbles)	0.00000795	0.00001430	0.001430	
Copper	0.00000887	0.00001596	0.001596	0.001718
Ebonite	0.00004278	0.00007700	0.007700	
Glass, English flint	0.00000451	0.00000812	0.000812	
Glass, thermometer	0.00000499	0.00000897	0.000897	
Glass, hard	0.00000397	0.00000714	0.000714	
Granite, gray, dry	0.00000438	0.00000789	0.000789	
Granite, red, dry	0.00000498	0.00000897	0.000897	
Gold, pure	0.00000786	0.00001415	0.001415	
Iridium, pure	0.00000356	0.00000641	0.000641	
Iron, wrought	0.00000648	0.00001166	0.001166	0.001235
Iron, cast	0.00000556	0.00001001	0.001001	0.001110
Lead	0.00001571	0.00002828	0.002828	
Magnesium	....	....	....	0.002694
Marbles, various, from	0.00000308	0.00000554	0.000554	
Marbles, various, to	0.00000786	0.00001415	0.001415	
Masonry, brick, from	0.00000256	0.00000460	0.000460	
Masonry, brick, to	0.00000494	0.00000890	0.000890	
Mercury (cubic expansion)	0.00009984	0.00017971	0.017971	0.018018
Nickel	0.00000695	0.00001251	0.001251	0.001279
Pewter	0.00001129	0.00002033	0.002033	
Plaster, white	0.00000922	0.00001660	0.001660	
Platinum	0.00000479	0.00000863	0.000863	
Platinum, 85 per cent, iridium 15 per cent	0.00000453	0.00000815	0.000815	0.000884
Porcelain	0.00000200	0.00000360	0.000360	
Quartz, parallel to major axis, 0° to 40° C.	0.00000434	0.00000781	0.000781	
Quartz, perpendicular to major axis, 0° to 40° C.	0.00000788	0.00001419	0.001419	
Silver, pure	0.00001079	0.00001943	0.001943	0.001908
Slate	0.00000577	0.00001038	0.001038	
Steel, cast	0.00000636	0.00001144	0.001144	0.001079
Steel, tempered	0.00000689	0.00001240	0.001240	
Stone (sandstone), dry	0.00000652	0.00001174	0.001174	
Stone (sandstone), Rauville	0.00000417	0.00000750	0.000750	
Tin	0.00001163	0.00002094	0.002094	0.001938
Wedgwood ware	0.00000489	0.00000881	0.000881	
Wood, pine	0.00000276	0.00000496	0.000496	
Zinc	0.00001407	0.00002532	0.002532	0.002942
Zinc, 8, tin, 1	0.00001496	0.00002692	0.002692	
Invar	0.0000005	0.0000010		
Aterite	0.0000095	0.0000171		

* Clark, "Rules, Table and Data for Mechanical Engineers."

Expansion of Steel at High Temperatures

Composition of steels				Mean coefficients of expansion from			Coefficients between	
C	Mn	Si	P	1.5° to 200°	200° to 500°	500° to 650°		
0.03	0.01	0.03	0.013	11.8×10^{-6}	14.3×10^{-6}	17.0×10^{-6}	24.5×10^{-6}	880° and 950°
0.25	0.04	0.05	0.010	11.5	14.5	17.5	23.3	800° and 950°
0.64	0.12	0.14	0.009	12.1	14.1	16.5	23.3	720° and 950°
0.93	0.10	0.05	0.005	11.6	14.9	16.0	27.5	720° and 950°
1.23	0.10	0.08	0.005	11.9	14.3	16.5	33.8	720° and 950°
1.50	0.04	0.09	0.010	11.5	14.9	16.5	36.7	720° and 950°
3.50	0.03	0.07	0.005	11.2	14.2	18.0	33.3	720° and 950°

Nickel steels			Mean coefficients of expansion from				
Ni	C	Mn	15° to 100°	100° to 200°	200 to 400°	400° to 600°	600° to 900°
26.9	0.35	0.30	11.0×10^{-6}	18.0×10^{-6}	18.7×10^{-6}	22.0×10^{-6}	23.0×10^{-6}
28.9	0.35	0.36	10.0	21.5	19.0	20.0	22.7
30.1	0.35	0.34	9.5	14.0	19.5	19.0	21.3
34.7	0.36	0.36	2.0	2.5	11.75	19.5	20.7
36.1	0.39	0.39	1.5	1.5	11.75	17.0	20.3
32.8	0.29	0.66	8.0	14.0	18.0	21.5	22.3
35.8	0.31	0.69	2.5	2.5	12.5	18.75	19.3
37.4	0.30	0.69	2.5	1.5	8.5	19.75	18.3
25.4	1.01	0.79	12.5	18.5	19.75	21.0	35.0
29.4	0.99	0.89	11.0	12.5	19.0	20.5	31.7
34.5	0.97	0.84	3.0	3.5	13.0	18.75	26.7

Thermal Expansion of Iron and Steel Tubes

A number of samples of the various metals used in the manufacture of seamless and welded tubes were recently submitted to the Bureau of Standards, Washington, D. C., for determinations of the coefficients of expansion within the range of temperatures common to boiler practice. The mean coefficient of expansion (a) of these materials between 0° C. and 200° C. was found to be:

	Chemical Analyses				(a)
	Carbon	Phosphorus	Manganese	Sulphur	
Charcoal iron..........	Trace	0.049	Trace	0.020	0.00001235
Bessemer steel.........	0.07	0.132	0.40	0.052	0.00001258
Seamless open-hearth steel (hot finished)....	0.12	0.0145	0.51	0.035	0.00001239

The length of a tube at t degrees Centigrade is:

$$L_t = L_0(1 + at).$$

The report of this investigation contains the following remark:

"As might have been expected from the known behavior of metals, nearly all the specimens appeared to expand faster at higher than at low temperatures. The measurements indicate that, throughout the range from 0° C. to 200° C., the values of the coefficients (a) might increase from as much as about 1.3 per cent less than to about as much as 1.3 per cent greater than the values given in the above table."

The volume of a perfect gas increases 1/273.1 of its volume at 0° C. for every increase of temperature of 1° C., and decreases 1/273.1 of its volume at 0° C. for every decrease of temperature of 1° C. At −273.1° C. the volume would then be reduced to nothing. This point, −273.1° C. = −459.6° F., or 491.6° F. below the temperature of melting ice, is called the absolute zero, and absolute temperatures are measured on either the Centigrade or the Fahrenheit scale, from this zero. The freezing point, 32° F., corresponds to 491.6° F. absolute. If p_0 be the pressure and v_0 the volume of a perfect gas at 32° F. = 491.6° absolute, $= T_0$, and p the pressure and v the volume of the same weight of gas at any other absolute temperature, T, then

$$\frac{pv}{p_0v_0} = \frac{T}{T_0} = \frac{t + 459.6}{491.6}; \quad \frac{pv}{T} = \frac{p_0v_0}{T_0} = R.$$

A cubic foot of dry air at 32° F. at sea level (barometer = 29.921 inches of mercury) weighs 0.080728 pound. The volume of 1 pound is 1/0.080728 = 12.387 cubic feet. The pressure is 2116.3 pounds per square foot.

$$R = \frac{p_0v_0}{T_0} = \frac{2116.3 \times 12.387}{491.6} = \frac{26,214}{491.6} = 53.32.$$

Tenacity of Metals at Various Temperatures

The British Admiralty made a series of experiments to ascertain what loss of strength and ductility takes place in gun-metal compositions when raised to high temperatures. It was found that all the varieties of gun-metal suffer a gradual but not serious loss of strength and ductility up to a certain temperature, at which, within a few degrees, a great change takes place, the strength falls to about one-half the original, and the ductility is wholly gone. At temperatures above this point, up to 500° F., there is little, if any, further loss of strength; the temperature at which this great change and loss of strength takes place, although uniform in the specimens cast from the same pot, varies about 100° in the same composition cast at different temperatures, or with some varying conditions in the foundry process. The temperature at which the change took place in No. 1 series was ascertained to be about 370°, and in that of No. 2, at a little over 250°. Rolled Muntz metal and copper are satisfactory up to 500°, and may be used as securing-bolts with safety. Wrought iron increases in strength up to 500°, but loses slightly in ductility up to 300°, where an increase begins and continues up to 500°, where it is still less than at the ordinary temperature of the atmosphere. The strength of Landore steel is not affected by temperature up to 500°, but its ductility is reduced more than one-half. (Iron, Oct. 6, 1877.)

Strength of iron and steel boiler-plate at high temperatures.—(Chas. Huston, Jour. F. I., 1877.)

Average of Three Tests of Each

Temperature F.	68°	575°	925°
Charcoal iron plate, tensile strength, pounds	55,366	63,080	65,343
Charcoal iron plate, contr. of area, per cent	26	23	21
Soft open-hearth steel, tensile strength, pounds	54,600	66,083	64,350
Soft open-hearth steel, contr., per cent	47	38	33
Soft Crucible steel, tensile strength, pounds	64,000	69,266	68,600
Soft Crucible steel, contr., per cent	36	30	21

Tensile strength of iron and steel at high temperatures.—James E. Howard's tests (Iron Age, April 10, 1890) show that the tensile strength of steel diminishes as the temperature increases from 0° until a minimum is reached between 200° and 300° F., the total decrease being about 4000 pounds per square inch in the softer steels, and from 6000 to 8000 pounds in steels of over 80,000 pounds tensile strength. From this minimum point the strength increases up to a temperature of 400° to 650° F., the maximum being reached earlier in the harder steels, the increase amounting to from 10,000 to 20,000 pounds per square inch above the minimum strength at from 200° to 300°. From this maximum, the strength of all the steel decreases steadily at a rate approximating 10,000 pounds decrease per 100° increase of temperature. A strength of 20,000 pounds per square inch is still shown by 0.10 C. steel at about 1000° F., and by 0.60 to 1.00 C. steel at about 1600° F.

The strength of wrought iron increases with temperature from 0° up to a maximum at from 400° to 600° F., the increase being from 8000 to 10,000 pounds per square inch, and then decreases steadily till a strength of only 6000 pounds per square inch is shown at 1500° F.

Cast iron appears to maintain its strength, with a tendency to increase, until 900° is reached, beyond which temperature the strength gradually diminishes. Under the highest temperatures, 1500° to 1600° F., numerous cracks on the cylindrical surface of the specimen were developed prior to rupture. It is remarkable that cast iron, so much inferior in strength to the steels at atmospheric temperature, under the highest temperatures has nearly the same strength the high-temper steels then have.

Strength of wrought iron and steel at high temperatures.—(Jour. F. I., CXII, 1881, page 241.)—Kollmann's experiments at Oberhausen included tests of the tensile strength of iron and steel at temperatures ranging between 70° and 2000° F. Three kinds of metal were tested, viz., fibrous iron of 52,464 pounds T. S., 38,280 pounds E. L., and 17.5 per cent elong.; fine-grained iron of 56,892 pounds, T. S., 39,113 pounds E. L., and 20 per cent elong.; and Bessemer steel of 84,826 pounds T. S., 55,029 pounds E. L., and 14.5 per cent elong. The mean ultimate tensile strength of each material expressed in per cent of its tensile strength at ordinary atmospheric temperature is given in the following table, the fifth column of which exhibits, for purposes of comparison, the results of experiments by a committee of the Franklin Institute in the years 1832–36.

Effect of cold on the strength of iron and steel.—The following conclusions were arrived at by Mr. Styffe in 1865:

(1) The absolute strength of iron and steel is not diminished by cold, even at the lowest temperature which ever occurs in Sweden.

(2) Neither in steel nor in iron is the extensibility less in severe cold than at the ordinary temperature.

(3) The limit of elasticity in both steel and iron lies higher in severe cold.

(4) The modulus of elasticity in both steel and iron is increased on reduction of temperature, and diminished on elevation of temperature; but these variations never exceed 0.05 per cent for a change of 1.8° F.

Temperature, degrees F.	Fibrous iron, per cent	Fine-grained iron, per cent	Bessemer steel, per cent	Franklin Institute, per cent
0	100.0	100.0	100.0	96.0
100	100.0	100.0	100.0	102.0
200	100.0	100.0	100.0	105.0
300	97.0	100.0	100.0	106.0
400	95.5	100.0	100.0	106.0
500	92.5	98.5	98.5	104.0
600	88.5	95.5	92:0	99.5
700	81.5	90.0	68.0	92.5
800	67.5	77.5	44.0	75.5
900	44.5	51.5	36.5	53.5
1000	26.0	36.0	31.0	36.0
1100	20.0	30.5	26.5	
1200	18.0	28.0	22.0	
1400	13.5	19.0	15.0	
1600	7.0	12.5	10.0	
1800	4.5	8.5	7.5	
2000	3.5	5.0	5.0	

W. H. Barlow (Proc. Inst. C. E.) made experiments on bars of wrought iron, cast iron, malleable cast iron, Bessemer steel, and tool steel. The bars were tested with tensile and transverse strains, and also by impact; one-half of them at a temperature of 50° F., and the other half at 5° F.

The results of the experiments were summarised as follows:

1. When bars of wrought iron or steel were submitted to a tensile strain and broken, their strength was not affected by severe cold (5° F.), but their ductility was increased about 1 per cent in iron and 3 per cent in steel.

2. When bars of cast iron were submitted to a transverse strain at a low temperature, their strength was diminished about 3 per cent and their flexibility about 16 per cent.

3. When bars of wrought iron, malleable cast iron, steel, and ordinary cast iron were subjected to impact at 5° F., the force required to break them, and their flexibility, were reduced as follows:

	Reduction of force of impact, per cent	Reduction of flexibility, per cent
Wrought iron, about	3	18
Steel (best cast tool), about	3½	17
Malleable cast iron, about	4½	15
Cast iron, about	21	Not taken

The experience of railways in Russia, Canada, and other countries where the winter is severe, is that the breakages of rails and tires are far more numerous in the cold weather than in the summer. On this account a softer class of steel is employed in Russia for rails than is usual in more temperate climates.

The evidence extant in relation to this matter leaves no doubt that the capability of wrought iron or steel to resist impact is reduced by cold. On the other hand, its static strength is not impaired by low temperatures.

Crane Special Brass

Tensile strength. Pounds per square inch

70° F.	300° F.	450° F.	500° F.	525° F.	550° F.	600° F.	750° F.	900° F.	1000° F.
36,500	33,100	30,500	26,400	.....	16,350	16,300	13,375	.....	6400
36,050	34,350	26,150	26,950	.....	17,280	15,200	11,700	.....	....
.....	.....	24,940	30,500	.....	20,250	.....	11,800	.....	....
.....	.....	.....	.....	.....	17,750	.....	......	.....	....
33,700	34,600	29,250	28,300	15,300	16,950	14,800	14,580	9530	....
35,700	35,000	27,300	28,650	15,700	16,350	18,200	13,550	.....	....
34,780	.....	.....	.....	.....	15,500	16,000	......	.....	....
Av. 35,345	34,260	27,630	28,160	15,500	17,200	16,100	13,000	9530	6400

Crane Cast Monel Metal

Tensile strength. Pounds per square inch

70° F.	285° F.	435° F.	450° F.	600° F.	750° F.	1030° F.
53,450	......	......	47,200	38,850	42,800	......
.....	......	......	......	39,150	42,300	......
52,100	46,900	55,800	......	40,900	40,850	25,600
55,350	57,000	52,400	......	38,900	41,200	27,200
51,460	55,500	......	......	......	......	......
52,000	......	......	......	......	......	......
Av. 52,870	53,130	54,100	47,200	39,450	41,787	26,400

Crane Soft Cast Iron

Tensile strength. Pounds per square inch

70° F.	300° F.	450° F.	600° F.	750° F.	860° F.	1000° F.
22,210	23,260	20,730	20,250	24,660	......	18,760
21,300	......	......	19,510	22,670	......	18,890
23,900	......	......	20,120	......	......	21,410
......	......	......	21,020	......	......	18,610
23,170	......	......	22,040	20,860	......	......
21,690	......	......	22,970	20,100	......	......
20,760	......	......	22,790	22,010	21,590	21,450
21,360	......	......	......	21,250	......	......
Av. 22,060	23,260	20,730	21,240	21,925	21,590	19,820

Crane Malleable Iron

Tensile strength. Pounds per square inch

70° F.	300° F.	416° F.	450° F.	600° F.	655° F.	710° F.	750° F.	822° F.	950° F.
38,070	32,480	32,960	30,760	31,300	33,940	33,050	31,000	31,830	25,710
36,800	32,030	.....	33,480	34,990	.....	.....	33,930	.....	31,170
38,130	.....	.....	.....	34,690	.....	.....	.....	.....	26,010
38,580	32,470	.....	33,400	34,220	.....	.....	36,360	.....	27,790
36,540	33,080	.....	35,470	34,910	.....	.....	33,670	.....	24,880
.....	37,470	.....	.....	33,780	.....	.....	35,470	......	......
.....	.....	.....	.....	.....	.....	.....	34,910	......	......
Av. 37,625	33,505	32,960	33,280	34,000	33,940	33,050	34,055	31,830	27,110

Crane Ferrosteel

Tensile strength. Pounds per square inch

70° F.	300° F.	450° F.	600° F.	750° F.	873° F.	900° F.	1000° F.
30,660	30,940	32,440	32,200	31,530	....	....	26,530
31,450	30,530	33,720	32,980	29,980	....	....	26,430
32,850	....	....	....	....	....	....	28,190
......	....	....	....	....	....	....	26,450
33,970	31,640	33,310	30,620	30,960	33,420	....	29,770
31,090	36,400	....	33,780	33,960	....	....	28,380
31,280	34,450	....	....	....	....	....	28,740
35,240	35,450	34,850	32,710	33,490	....	27,200	28,280
34,750	33,600	32,700	35,880	35,310	....	24,350	27,920
32,850	....	....	33,600	34,800	....	....	25,350
Av. 32,692	33,290	33,400	33,110	23,860	33,420	25,780	27,310

Crane Cast Steel

Tensile strength. Pounds per square inch

70° F.	300° F.	450° F.	600° F.	720° F.	750° F.	1000° F.
72,000	77,000	80,000	66,080	64,000	......	19,270
72,100	74,500	......	70,000	60,000	......	21,000
......	77,000	......	68,800	57,150	......	......
77,100	77,100	82,750	63,200	53,700	41,000	17,800
72,100	77,250	80,750	68,750	......	40,250	12,200
......	......	......	......	......	40,100	......
......	......	......	......	......	44,200	......
Av. 73,325	76,570	81,167	67,366	58,713	41,388	17,568

CRANE CAST STEEL—*Continued*

Elastic limit. Pounds per square inch

70° F.	300° F.	490° F.	600° F.	720° F.	750° F.	1000° F.
......	28,750	31,500	27,300	31,000	......	13,400
38,600	40,000	......	28,000	......	......	......
......	34,250	......	32,000	36,000	......	......
......	......	......	27,750	......	......	......
43,400	34,000	40,550	29,730	32,940	26,200	7,050
37,450	33,100	30,750	31,750	......	28,250	8,500
......	......	......	......	......	27,220	......
Av. 39,817	34,020	34,267	29,422	33,313	27,223	9,650

ROLLED ROD BRASS

Tensile strength. Pounds per square inch

	70° F.	300° F.	450° F.	600° F.	750° F.	900° F.
	54,600	52,700	49,000	34,800	18,740	10,170
	54,300	......	......	35,300	....	....
Av.	54,450	52,700	49,000	35,050	18,740	10,170

Elastic limit. Pounds per square inch

	70° F.	300° F.	450° F.	600° F.	750° F.	900° F.
	44,200	43,200	39,100	25,070	15,050	8,060
	45,800	....	....	22,400	....	....
Av.	45,000	43,200	39,100	23,735	15,050	8,060

Elongation. Per cent in 2 inches

	70° F.	300° F.	450° F.	600° F.	750° F.	900° F.
	15.6	26.6	21.9	14.1	17.2	21.9
	17.2	......	......	15.6	......	......
Av.	16.4	26.6	21.9	14.9	17.2	21.9

ROLLED MONEL METAL

	70° F.	300° F.	450° F.	525° F.	600° F.	750° F.	1030° F.
Tensile strength. Pounds per square inch							
	105,000	97,400	97,800	96,400	89,600	67,600	47,200
	104,800	......	......	......	......	......	......
Av.	104,900	97,400	97,800	96,400	89,600	67,600	47,200
Elastic limit. Pounds per square inch							
	74,200	58,500	58,600	58,400	57,950	42,550	26,800
	82,500	......	......	......	......	......	......
Av.	78,350	58,500	58,600	58,400	57,950	42,550	26,800
Elongation. Per cent in 2 inches							
	31.3	29.7	29.7	32.8	32.8	28.1	28.1
	31.3	......	......	......	......	......	......
Av.	31.3	29.7	29.7	32.8	32.8	28.1	28.1
Reduction of area. Per cent.							
	60.8	57.8	51.0	51.5	59.5	58.1	60.7
	62.5	......	......	......	......	......	......
Av.	61.7	57.8	51.0	51.5	59.5	58.1	60.7

Cold-Rolled Shafting (Bessemer)

	70° F.	300° F.	375° F.	450° F.	525° F.	600° F.	795° F.	950° F.
	Tensile strength. Pounds per square inch							
	82,800	91,850	93,350	95,600	96,250	90,600	59,500	41,200
	82,800	.....	.....	96,650	.....	86,450	.....	37,300
	......	.....	.....	96,000	.....	......	.....	......
Av.	82,800	91,850	93,350	96,083	96,250	88,525	59,500	39,250
	Elastic limit. Pounds per square inch							
	77,400	77,100	66,030	71,300	75,300	53,200	53,200	32,000
	76,200	.....	.....	74,400	.....	55,350	.....	28,800
Av.	76,800	77,100	66,030	72,850	75,300	54,275	53,200	30,400
	Elongation. Per cent in 2 inches							
	21.9	21.9	18.8	21.9	18.8	25.0	25.0	34.4
	21.9	.....	.....	21.9	.....	25.0	.....	35.9
	....	.....	.....	21.9	.....	.....	.....	.....
Av.	21.9	21.9	18.8	21.9	18.8	25.0	25.0	35.2
	Reduction of area. Per cent							
	49.9	39.1	36.8	38.8	37.5	43.6	58.5	78.6
	49.2	.....	.....	38.3	.....	44.9	.....	77.4
	....	.....	.....	39.1	.....	.....	.....	.....
Av.	49.5	39.1	36.8	38.7	37.5	44.2	58.5	78.0

Latent Heats of Fusion and Evaporation

Latent heat means a quantity of heat which has disappeared, having been employed to produce some change other than elevation of temperature. By exactly reversing that change, the quantity of heat which has disappeared is reproduced. Maxwell defines it as the quantity of heat which must be communicated to a body in a given state in order to convert it into another state without changing its temperature.

Latent heat of fusion.—When a body passes from the solid to the liquid state, its temperature remains stationary, or nearly stationary, at a certain melting point during the whole operation of melting; and in order to make that operation go on, a quantity of heat must be transferred to the substance melted, being a certain amount for each unit of weight of the substance. This quantity is called the latent heat of fusion.

When a body passes from the liquid to the solid state, its temperature remains stationary, or nearly stationary, during the whole operation of freezing; a quantity of heat equal to the latent heat of fusion is produced in the body and released into the atmosphere or other surrounding bodies.

The following are examples in British thermal units per pound, as given in Landolt and Börnstein's "Physikalische-Chemische Tabellen" (Berlin 1894).

Substances	Latent heat of fusion	Substances	Latent heat of fusion
Bismuth	22.75	Silver	37.93
Cast iron, gray	41.4	Beeswax	76.14
Cast iron, white	59.4	Paraffin	63.27
Lead	9.66	Spermaceti	66.56
Tin	25.65	Phosphorus	9.06
Zinc	50.63	Sulphur	16.86

The latent heat of fusion of ice is generally taken at 144 B.t.u. per pound. The U. S. Bureau of Standards (1915) gives it as 79.76 20°-calories per gram = 143.56 B.t.u. per pound.

Latent heat of evaporation.—When a body passes from the solid or liquid to the gaseous state, its temperature during the operation remains stationary at a certain boiling point, depending on the pressure of the vapor produced; and in order to make the evaporation go on, a quantity of heat must be transferred to the substance evaporated, whose amount for each unit of weight of the substance evaporated depends on the temperature. That heat does not raise the temperature of the substance, but disappears in causing the substance to assume the gaseous state, and is called the latent heat of evaporation.

When a body passes from the gaseous state to the liquid or solid state, its temperature remains stationary, during that operation, at the boiling point corresponding to the pressure of the vapor; a quantity of heat equal to the latent heat of evaporation at that temperature is produced in the body; and in order that the operation of condensation may go on, that heat must be transferred from the body condensed to some other body.

The following are examples of the latent heat of evaporation in British thermal units, of one pound of certain substances, when the pressure of the vapor is one atmosphere of 14.7 pounds on the square inch:

Substance	Boiling point under 1 atmosphere F°.	Latent heat in British units
Water	212.0	965.7 (Regnault)
Alcohol	172.2	364.3 (Andrews)
Ether	95.0	162.8 (Andrews)
Bisulphide of carbon	114.8	156.0 (Andrews)

The total heat of evaporation is the sum of the heat which disappears in evaporating one pound of a given substance at a given temperature (or latent heat of evaporation) and of the heat required to raise its temperature, before evaporation, from some fixed temperature up to the temperature of evaporation. The latter part of the total heat is called the sensible heat.

Radiation of Heat

Radiation of heat takes place between bodies at all distances apart, and follows the laws for the radiation of light.

The heat rays proceed in straight lines, and the intensity of the rays radiated from any one source varies inversely as the square of their distance from the source.

This statement has been erroneously interpreted by some writers, who have assumed from it that a boiler placed 2 feet above a fire would receive by radiation only one-fourth as much heat as if it were only 1 foot above the fire. In the case of boiler furnaces the side walls reflect those rays that are received at an angle—following the law of optics, that the angle of incidence is equal, to the angle of reflection—with the result that the intensity of heat 2 feet above the fire is practically the same as at 1 foot above, instead of only one-fourth as much.

The rate at which a hotter body radiates heat, and a colder body absorbs heat, depends upon the state of the surfaces of the bodies as well as on their temperatures. The rates of radiation and of absorption are increased by darkness and roughness of the surfaces of the bodies, and diminished by smoothness and polish. For this reason the covering of steam pipes and boilers should be smooth and of a light color; uncovered pipes and steam-cylinder covers should be polished.

The quantity of heat radiated by a body is also a measure of its heat-absorbing power under the same circumstances. When a polished body is struck by a ray of heat, it absorbs part of the heat and reflects the rest. The reflecting power of a body is therefore the complement of its absorbing power, which latter is the same as its radiating power.

Relative Radiating and Reflecting Power of Different Substances

	Radiating or absorbing power	Reflecting power		Radiating or absorbing power	Reflecting power
Lampblack	100	0	Zinc, polished	19	81
Water	100	0	Steel, polished	17	83
Carbonate of lead	100	0	Platinum, polished	24	76
Writing-paper	98	2	Platinum in sheet	17	83
Ivory, jet, marble	93 to 98	7 to 2	Tin	15	85
Ordinary glass	90	10	Brass, cast, dead polished	11	89
Ice	85	15	Brass, bright polished	7	93
Gum lac	72	28	Copper, varnished	14	86
Silver-leaf on glass	27	73	Copper, hammered	7	93
Cast iron, bright polished	25	75	Gold, plated	5	95
Mercury, about	23	77	Gold on polished steel	3	97
Wrought iron, polished	23	77			

Conduction and Convection of Heat

Conduction is the transfer of heat between two bodies or parts of a body which touch each other. Internal conduction takes place between the parts of one continuous body, and external conduction through the surface of contact of a pair of distinct bodies.

The rate at which conduction, whether internal or external, goes on, being proportional to the area of the section or surface through which it takes place, may be expressed in thermal units per square foot of area per hour.

Internal conduction varies with the *heat conductivity*, which depends upon the nature of the substance, and is directly proportional to the difference between the temperatures of the two faces of a layer, and inversely as its thickness. The reciprocal of the conductivity is called the *internal thermal resistance* of the substance. If r represents this resistance, x the thickness of the layer in inches, T' and T the temperatures on the two faces, and q the quantity in thermal units transmitted per hour per square foot of area,

$$q=\frac{T'-T}{rx}. \quad \text{(Rankine)}$$

Péclet gives the following values of r:

Gold, platinum, silver	0.0016	Lead	0.0090
Copper	0.0018	Marble	0.0716
Iron	0.0043	Brick	0.1500
Zinc	0.0045		

Relative Heat-conducting Power of Metals

Metals	*C. & J.	†W. & F.	Metals	*C. & J.	†W. & F.
Silver	1000	1000	Cadmium	577	
Gold	981	532	Wrought iron	436	119
Gold, with 1 per cent of silver	840		Tin	422	145
Copper, rolled	845	736	Steel	397	116
Copper, cast	811		Platinum	380	84
Mercury	677		Sodium	365	
Mercury, with 1.25 per cent of tin	412		Cast iron	359	
Aluminum	665		Lead	287	85
Zinc:			Antimony:		
Cast vertically	628		Cast horizontally	215	
Cast horizontally	608		Cast vertically	192	
Rolled	641		Bismuth	61	18

* Calvert & Johnson. † Weidemann & Franz.

Influence of a Non-metallic Substance in Combination on the Conducting Power of a Metal

Influence of carbon on iron:		Cast copper	811
Wrought iron	436	Copper with 1 per cent of arsenic	570
Steel	397	Copper, with 0.5 per cent of arsenic	669
Cast iron	359	Copper, with 0.25 per cent of arsenic	771

The rate of external conduction through the bounding surface between a solid body and a fluid is approximately proportional to the difference of temperature, when that is small; but when that difference is considerable, the rate of conduction increases faster than the simple ratio of that difference. (Rankine.)

If r, as before, is the coefficient of internal thermal resistance, e and e' the coefficient of external resistance of the two surfaces, x the thickness of the plate, and T' and T the temperatures of the two fluids in contact with the two surfaces, the rate of conduction is

$$q=\frac{T'-T}{e+e'+rx}.$$

According to Péclet,

$$e+e'=\frac{1}{A[1+B(T'-T)]},$$

in which the constants A and B have the following values:

B for polished metallic surfaces	0.0028
B for rough metallic surfaces and for non-metallic surfaces	0.0037
A for polished metals, about	0.90
A for glassy and varnished surfaces	1.34
A for dull metallic surfaces	1.58
A for lampblack	1.78

When a metal plate has a liquid at each side of it, it appears from experiments by Péclet that $B=0.058$, $A=8.8$.

The results of experiments on the evaporative power of boilers agree very well with the following approximate formula for the thermal resistance of boiler plates and tubes:

$$e+e'=\frac{a}{(T'-T)},$$

which gives for the rate of conduction, per square foot of surface per hour,

$$q=\frac{(T'-T)^2}{a}.$$

This formula is proposed by Rankine as a rough approximation, near enough to the truth for its purpose. The value of a lies between 160 and 200. Experiments on modern boilers usually give higher values.

Convection, or carrying of heat, means the transfer and diffusion of the heat in a fluid mass by means of the motion of the particles of that mass.

The conduction, properly so called, of heat through a stagnant mass of fluid is very slow in liquids, and almost, if not wholly, inappreciable in gases. It is only by the continual circulation and mixture of the particles of the fluid that uniformity of temperature can be maintained in the fluid mass, or heat transferred between the fluid mass and a solid body.

The free circulation of each of the fluids which touch the side of a solid plate is a necessary condition of the correctness of Rankine's formulae for the conduction of heat through that plate; and in these formulae it is implied that the circulation of each of the fluids by currents and eddies is such as to prevent any considerable difference in temperature between the fluid particles in contact with one side of the solid plate and those at considerable distances from it.

When heat is to be transferred by convection from one fluid to another, through an intervening layer of metal, the motions of the two fluid masses should, if possible, be in

opposite directions, in order that the hottest particles of each fluid may be in communication with the hottest particles of the other, and that the minimum difference of temperature between the adjacent particles of the two fluids may be the greatest possible.

Thus, in the surface condensation of steam, by passing it through metal tubes immersed in a current of cold water or air, the cooling fluid should be made to move in the opposite direction to the condensing steam.

Heat Conducting and Resisting Values of Different Materials

Insulating material	Conductance, B.t.u. per square foot per day per degree difference of temperature	Coefficient of heat resistance, C.
1. ⅝-inch oak board, 1 inch lampblack, ⅞-inch pine board (ordinary family refrigerator)	5.7	4.21
2. ⅞-inch board, 1 inch pitch, ⅞-inch board	4.89	4.91
3. ⅞-inch board, 2 inches pitch, ⅞-inch board	4.25	5.65
4. ⅞-inch board, paper, 1 inch mineral wool, paper, ⅞-inch board	4.6	5.22
5. ⅞-inch board, paper, 2½ inches mineral wool, paper, ⅞-inch board	3.62	6.63
6. ⅞-inch board, paper, 2½ inches calcined pumice, ⅞-inch board	3.38	7.10
7. Same as above, when wet	3.90	6.15
8. ⅞-inch board, paper, 3 inches sheet cork, ⅞-inch board	2.10	11.43
9. Two ⅞-inch boards, paper, solid, no air space, paper, two ⅞-inch boards	4.28	5.61
10. Two ⅞-inch boards, paper, 1 inch air space, paper, two ⅞-inch boards	3.71	6.47
11. Two ⅞-inch boards, paper, 1 inch hair felt, paper, two ⅞-inch boards	3.32	7.23
12. Two ⅞-inch boards, paper, 8 inches mill shavings, paper, two ⅞-inch boards	1.35	17.78
13. The same, slightly moist	1.80	13.33
14. The same, damp	2.10	11.43
15. Two ⅞-inch boards, paper, 3 inches air, 4 inches sheet cork, paper, two ⅞-inch boards	1.20	20.00
16. Same, with 5 inches sheet cork	0.90	26.67
17. Same, with 4 inches granulated cork	1.70	14.12
18. Same, with 1 inch sheet cork	3.30	7.27
19. Four double ⅞-inch boards (8 boards), with paper between, three 8-inch air spaces	2.70	8.89
20. Four ⅞-inch boards, with three quilts of ¼-inch hair between, papers separating boards	2.52	9.52
21. ⅞-inch board, 6 inches patented silicated strawboard, finished inside with thin cement	2.48	9.68

Transmission of heat from steam to water through coils of iron pipe.—H. G. C. Kopp and F. J. Meystre (Stevens Indicator, Jan., 1894) give an account of some experiments on transmission of heat through coils of pipe. They collate the results of earlier experiments as follows, for comparison:

Experimenter	Character of surface	Steam condensed per square foot per degree difference of temperature per hour		Heat transmitted per square foot per degree difference of temperature per hour		Remarks
		Heating, pounds	Evaporating, pounds	Heating, B.t.u.	Evaporating, B.t.u.	
Laurenz..	Copper coils.....	0.292	0.981	315	974	
Laurenz..	2 copper coils....	....	1.20	....	1120	
Havrez...	Copper coil......	0.268	1.26	280	1200	
Perkins...	Iron coil........	....	0.24	....	215	Steam pressure = 100
Perkins...	Iron coil........	....	0.22	....	208.2	Steam pressure = 10
Box......	Iron tube.......	0.235	....	230		
Box......	Iron tube.......	0.196	....	207		
Box......	Iron tube.......	0.206	....	210		
Havrez...	Cast-iron boiler..	0.077	0.105	82	100	

Heating water by steam coils.—A catalogue of the American Radiator Co. (1908) gives a chart showing the pounds of steam condensed per hour per square foot of iron, brass and copper pipe surface, for different mean or average differences of temperature between the steam and the water. Taking the latent heat of the steam at 966 B.t.u. per pound, the following figures are derived from the table:

Mean temperature difference	Pounds steam condensed per hour per square foot of pipe			Pounds steam condensed per hour per square foot per degree difference			B.t.u. per square foot per hour per degree difference		
	Iron	Brass	Copper	Iron	Brass	Copper	Iron	Brass	Copper
50	7.5	12.5	14.5	0.150	0.250	0.290	101	198	280
100	18.5	38	43.5	0.185	0.380	0.435	179	367	415
150	32.2	76.5	87.8	0.215	0.510	0.535	208	493	565
200	48	128	144	0.240	0.640	0.720	232	618	696

The chart is said to have been plotted from a large number of tests with pipes placed vertically in a tank of water, about 20 per cent being deducted from the actual results as a margin of safety.

Cooling of air.—H. F. Benson (Am. Mach., Aug. 31, 1905) derives the following formula for transmission of heat from air to water through copper tubes. It is assumed that the rate of transmission at any point of the surface is directly proportional to the difference of temperature between the air and water.

Let A = cooling surface, square feet;
K = pounds of air per hour;
S_a = specific heat of air;
T_{a1} = temperature of hot inlet air;
T_{a2} = temperature of cooled outlet air;
d = actual average difference of temperature between the air and the water;
U = B.t.u. absorbed by the water per degree of difference of temperature per square foot per hour.
W = pounds of water per hour;
T_{w1} = temperature of inlet water;
T_{w2} = temperature of outlet water Then

$$AdU = KS_a(T_{a1} - T_{a2}); \quad A = KS_a(T_{a1} - T_{a2}) \div dU.$$

$$d = [(T_{a1} - T_{a2}) - (T_{w2} - T_{w1})] \div \log [(T_{a1} - T_{w2}) \div (T_{a2} - T_{w1})].$$

$$AU = \frac{KS_aW}{W - KS_a} \log_e \frac{T_{a1} - T_{w2}}{T_{a2} - T_{w1}}.$$

$$T_{w2} = (S_aK \div W)(T_{a1} - T_{a2}) + T_{w1}.$$

The more cooling water used, the lower is the temperature T_{w2}. Also the less T_{w2} is, the larger d becomes and the less surface is needed. About 10 is the largest value of W/K that it is economical to use, as there is a saving of less than 0.5 per cent in increasing it from 10 to 15. When it is desirable to save water it will be advisable to make $W/K = 5$. Values of U obtained by experiment with a Wainwright cooler made with corrugated copper tubes are given in the following table. K and W are in pounds per minute, B_a = B.t.u. from air per minute, B_w = B.t.u. from water per minute, V_w = velocity of water, feet per minute.

T_{a1}	T_{a2}	T_{w1}	T_{w2}	K	W	B_a	B_w	V_w	U
221.0	76.3	50.0	169.0	125.2	28.50	4303	3392	2.20	6.75
217.0	64.3	45.8	146.4	122.8	36.73	4452	3695	2.84	7.12
224.0	63.3	45.7	149.2	126.3	40.30	4819	4171	3.11	7.91
209.6	54.0	43.8	125.9	122.1	50.00	4511	4105	3.86	8.81
214.5	46.3	43.0	106.2	124.6	68.95	4976	4357	5.32	10.55
234.6	63.6	52.6	120.2	124.4	73.25	5051	4852	5.65	8.41
214.2	43.5	43.0	94.7	117.3	79.84	4753	4128	6.16	14.32
242.9	61.7	55.3	114.0	133.6	92.72	5649	5443	7.15	10.01
223.0	46.0	40.1	79.1	130.5	114.80	5484	4477	8.86	7.86
239.3	57.5	51.0	95.2	130.0	125.70	5612	5556	9.70	9.38
246.0	58.0	52.3	95.1	133.8	145.90	5977	6244	11.26	10.57

Heat Units Lost by Convection from Horizontal Pipes per Square Foot of Surface per Hour, for a Temperature Difference of 1° F.

External diameter of pipe, inches	Heat units lost	External diameter of pipe, inches	Heat units lost	External diameter of pipe, inches	Heat units lost
2	0.728	7	0.509	18	0.455
3	0.626	8	0.498	24	0.447
4	0.574	9	0.489	36	0.438
5	0.544	10	0.482	48	0.434
6	0.523	12	0.472		

SPECIFIC GRAVITY

(See Testing Methods, page 594)

The specific gravity of a substance is its weight as compared with the weight of an equal bulk of pure water. In the metric system it is the weight in grams per cubic centimeter.

To find the specific gravity of a substance.—W = weight of body in air; w = weight of body submerged in water.

$$\text{Specific gravity} = \frac{W}{W-w}.$$

If the substance be lighter than the water, sink it by means of a heavier substance, and deduct the weight of the heavier substance.

Specific gravity determinations are usually referred to the standard of the weight of water at 62° F., 62.355 pounds per cubic foot. Some experimenters have used 60° F. as the standard, and others 32° and 39.1° F. There is no general agreement.

Given the specific gravity referred to water at 39.1° F., to reduce it to the standard of 62° F. multiply it by 1.00112.

Given the specific gravity referred to water at 62° F., to find weight per cubic foot multiply by 62.355. Given weight per cubic foot, to find specific gravity multiply by 0.016037. Given the specific gravity, to find weight per cubic inch multiply by 0.036085.

Specific Gravity of Liquids at 60° F.

Acid, muriatic	1.200	Oil, olive	0.92
Acid, nitric	1.54	Oil, palm	0.97
Acid, sulphuric	1.849	Oil, petroleum	0.78 to 0.88
Alcohol, pure	0.794	Oil, rape	0.92
Alcohol, 95 per cent	0.816	Oil, turpentine	0.86
Alcohol, 50 per cent	0.934	Oil, whale	0.92
Ammonia, 27.9 per cent	0.891	Tar	1.00
Bromine	2.97	Vinegar	1.08
Carbon disulphide	1.26	Water	1.00
Ether, sulphuric	0.72	Water, sea	1.026 to 1.03
Oil, linseed	0.93		

Weight and Specific Gravity of Stones, Brick, Cement, etc. (Pure water = 1.00)

	Pounds per cubic foot	Specific gravity
Ashes	43	
Asphaltum	87	1.39
Brick, soft	100	1.6
Brick, common	112	1.79
Brick, hard	125	2.0
Brick, pressed	135	2.16
Brick, fire	140 to 150	2.24 to 2.4
Brick, sand-lime	136	2.18
Brickwork in mortar	100	1.6
Brickwork in cement	112	1.79
Cement, American, natural	....	2.8 to 3.2
Cement, Portland	....	3.05 to 3.15
Cement, Portland, loose	92	
Cement, Portland, in barrel	115	
Clay	120 to 150	1.92 to 2.4
Concrete	120 to 155	1.92 to 2.48
Earth, loose	72 to 80	1.15 to 1.28
Earth, rammed	90 to 110	1.44 to 1.76
Emery	250	4
Glass	156 to 172	2.5 to 2.75
Glass, flint	180 to 196	2.88 to 3.14
Gneiss } Granite }	160 to 170	2.56 to 2.72
Gravel	100 to 120	1.6 to 1.92
Gypsum	130 to 150	2.08 to 2.4
Hornblende	200 to 220	3.2 to 3.52
Ice	55 to 57	0.88 to 0.92
Lime, quick, in bulk	50 to 60	0.8 to 0.96
Limestone	140 to 185	2.30 to 2.90
Magnesia, carbonate	150	2.4
Marble	160 to 180	2.56 to 2.88
Masonry, dry rubble	140 to 160	2.24 to 2.56
Masonry, dressed	140 to 180	2.24 to 2.88
Mica	175	2.80
Mortar	90 to 100	1.44 to 1.6
Mud, soft flowing	104 to 120	1.67 to 1.92
Pitch	72	1.15
Plaster of Paris	93 to 113	1.50 to 1.81
Quartz	165	2.64
Sand	90 to 110	1.44 to 1.76
Sand, wet	118 to 129	1.89 to 2.07
Sandstone	140 to 150	2.24 to 2.4
Slate	170 to 180	2.72 to 2.88
Soapstone	166 to 175	2.65 to 2.8
Stone, various	135 to 200	2.16 to 3.4
Stone, crushed	100	
Tile	110 to 120	1.76 to 1.92
Trap rock	170 to 200	2.72 to 3.4

Compression of Fluids under a Pressure of 15 Pounds per Square Inch

Water	0.00004663	Ether	0.00006158
Alcohol	0.0000216	Mercury	0.00000265

Specific Gravity and Weight of Gases at Atmospheric Pressure and 32° F.

(For other temperatures and pressures, see Physical Properties of Gases)

	Density, air = 1	Density, H = 1	Grams per liter	Pound per cubic foot	Cubic feet per pound
Air	1.0000	14.444	1.2931	0.080728	12.388
Oxygen, O	1.1052	15.963	1.4291	0.08921	11.209
Hydrogen, H	0.0692	1.000	0.0895	0.00559	178.931
Nitrogen, N	0.9701	14.012	1.2544	0.07831	12.770
Carbon monoxide, CO	0.9671	13.968	1.2505	0.07807	12.810
Carbon dioxide, CO_2	1.5197	21.950	1.9650	0.12267	8.152
Methane, marsh gas, CH_4	0.5530	7.987	0.7150	0.04464	22.429
Ethylene, C_2H_4	0.9674	13.973	1.2510	0.07809	12.805
Acetylene, C_2H_2	0.8982	12.973	1.1614	0.07251	13.792
Ammonia, NH_3	0.5889	8.506	0.7615	0.04754	21.036
Water vapor, H_2O	0.6218	8.981	0.8041	0.05020	19.922
Sulphur dioxide, SO_2	2.213	31.965	2.862	0.1787	5.597

Oil Equivalents Due to Specific Gravity

The Baumé degrees of the table and the corresponding specific gravities are for the standard temperature of 60° F.

The various values given opposite each degree Baumé are, however, independent of temperature; that is to say, with a given oil of any temperature, if the table is used in connection with the actual (uncorrected) reading of the hydrometer, the weights and relations given are those actually existing for the oil while at that temperature.

If the temperature changes, the Baumé degree will change, and the new values will be found from the new reading of the hydrometer.

For purposes of comparison, however, the temperature should always be noted.

For practical purposes, 60° F. (actually 59°) equals 15° C.

The Centigrade, or Celsius, thermometer divides the space between freezing point and boiling point into 100 divisions.

The Fahrenheit thermometer divides the same space into 180 divisions (212° − 32°).

Therefore, 1° C. = 1.8° F. and 1° F. = 0.555° C.

The Réaumur thermometer divides the space between freezing and boiling points into 80 divisions.

Therefore, 1° R. = 2.25° F. = 1.25° C.

The ratio of spaces is:

Réaumur = 4 divisions
Centigrade = 5 divisions
Fahrenheit = 9 divisions

Baumé	Specific gravity	Weight in Pounds			No. per Metric Ton (1000 kg. or 10 quintals)			No. per Long Ton (2240 lbs.)		U. S. gallons per Russian pood	Baumé
		U. S. gallons	Imperial gallons	Cubic feet	U. S. gallons	U. S. barrels	Cubic meters	U. S. barrels	Imperial gallons		
10	1.0000	8.33	10.00	62.30	264.72	6.303	1.002	6.404	223.96	4.336	10
11	0.9929	8.27	9.93	61.86	266.61	6.348	1.009	6.450	225.56	4.367	11
12	0.9859	8.21	9.86	61.42	268.50	6.393	1.016	6.495	227.16	4.398	12
13	0.9790	8.15	9.79	60.99	270.39	6.438	1.024	6.541	228.76	4.429	13
14	0.9722	8.10	9.72	60.57	272.28	6.483	1.031	6.587	230.36	4.460	14
15	0.9655	8.04	9.66	60.15	274.17	6.528	1.038	6.633	231.96	4.491	15
16	0.9589	7.99	9.59	59.74	276.06	6.573	1.045	6.678	233.56	4.522	16
17	0.9524	7.93	9.53	59.33	277.95	6.618	1.052	6.724	235.16	4.553	17
18	0.9459	7.88	9.46	58.93	279.84	6.663	1.059	6.770	236.76	4.584	18
19	0.9396	7.83	9.40	58.54	281.74	6.708	1.066	6.816	238.36	4.615	19
20	0.9333	7.77	9.33	58.15	283.63	6.753	1.074	6.861	239.96	4.646	20
21	0.9272	7.72	9.27	57.76	285.52	6.798	1.081	6.907	241.56	4.677	21
22	0.9211	7.67	9.21	57.38	287.41	6.843	1.088	6.953	243.16	4.708	22
23	0.9150	7.62	9.15	57.01	289.30	6.888	1.095	6.999	244.76	4.739	23
24	0.9091	7.57	9.09	56.64	291.19	6.933	1.102	7.044	246.36	4.770	24
25	0.9032	7.52	9.03	56.27	293.08	6.978	1.109	7.090	247.96	4.801	25
26	0.8974	7.47	8.98	55.91	294.97	7.023	1.117	7.136	249.56	4.832	26
27	0.8917	7.43	8.92	55.55	296.86	7.068	1.124	7.182	251.16	4.863	27
28	0.8861	7.38	8.86	55.20	298.75	7.113	1.131	7.227	252.76	4.894	28
29	0.8805	7.33	8.81	54.85	300.64	7.158	1.138	7.273	254.36	4.925	29
30	0.8750	7.29	8.75	54.51	302.53	7.203	1.145	7.319	255.96	4.956	30
31	0.8696	7.24	8.70	54.17	304.43	7.248	1.152	7.365	257.56	4.987	31
32	0.8642	7.20	8.64	53.84	306.32	7.293	1.160	7.410	259.16	5.017	32
33	0.8589	7.15	8.59	53.51	308.21	7.338	1.167	7.456	260.76	5.048	33
34	0.8537	7.11	8.54	53.18	310.10	7.383	1.174	7.502	262.36	5.079	34
35	0.8485	7.07	8.49	52.86	311.99	7.428	1.181	7.548	263.96	5.110	35
36	0.8434	7.02	8.44	52.54	313.88	7.473	1.188	7.593	265.56	5.141	36
37	0.8383	6.98	8.38	52.23	315.77	7.518	1.195	7.639	267.16	5.172	37
38	0.8333	6.94	8.33	51.92	317.66	7.563	1.202	7.685	268.75	5.203	38
39	0.8284	6.90	8.29	51.61	319.55	7.608	1.210	7.730	270.35	5.234	39
40	0.8235	6.86	8.24	51.31	321.44	7.653	1.217	7.776	271.95	5.265	40
41	0.8187	6.82	8.19	51.01	323.33	7.698	1.224	7.822	273.55	5.296	41
42	0.8140	6.78	8.14	50.71	325.22	7.743	1.231	7.868	275.15	5.327	42
43	0.8092	6.74	8.09	50.42	327.12	7.788	1.238	7.913	276.75	5.358	43
44	0.8046	6.70	8.05	50.13	329.01	7.833	1.245	7.959	278.35	5.389	44
45	0.8000	6.66	8.00	49.84	330.90	7.879	1.253	8.005	279.95	5.420	45
46	0.7955	6.62	7.96	49.56	332.79	7.924	1.260	8.051	281.55	5.451	46
47	0.7910	6.59	7.91	49.28	334.68	7.969	1.267	8.096	283.15	5.482	47
48	0.7865	6.55	7.87	49.00	336.57	8.014	1.274	8.142	284.75	5.513	48
49	0.7821	6.51	7.82	48.73	338.46	8.059	1.281	8.188	286.35	5.544	49
50	0.7778	6.48	7.78	48.45	340.35	8.104	1.288	8.234	287.95	5.575	50
51	0.7735	6.44	7.74	48.19	342.24	8.149	1.296	8.279	289.55	5.606	51
52	0.7692	6.41	7.69	47.92	344.13	8.194	1.303	8.325	291.15	5.637	52
53	0.7650	6.37	7.65	47.66	346.02	8.239	1.310	8.371	292.75	5.668	53
54	0.7609	6.34	7.61	47.40	347.91	8.284	1.317	8.417	294.35	5.699	54

Baumé	Specific gravity	Weight in Pounds			No. per Metric Ton (1000 kg. or 10 quintals)			No. per Long Ton (2240 lbs.)		U. S. gallons per Russian pood	Baumé
		U. S. gallons	Imperial gallons	Cubic feet	U. S. gallons	U. S. barrels	Cubic meters	U. S. barrels	Imperial gallons		
55	0.7568	6.30	7.57	47.15	349.81	8.329	1.324	8.462	295.95	5.730	55
56	0.7527	6.27	7.53	46.89	351.70	8.374	1.331	8.508	297.55	5.761	56
57	0.7487	6.24	7.49	46.64	353.59	8.419	1.338	8.554	299.15	5.792	57
58	0.7447	6.20	7.45	46.39	355.48	8.464	1.346	8.600	300.75	5.823	58
59	0.7407	6.17	7.41	46.15	357.37	8.509	1.353	8.645	302.35	5.854	59
60	0.7368	6.14	7.37	45.90	359.26	8.554	1.360	8.691	303.95	5.885	60
61	0.7330	6.10	7.33	45.66	361.15	8.599	1.367	8.737	305.55	5.916	61
62	0.7292	6.07	7.29	45.43	363.04	8.644	1.374	8.783	307.15	5.947	62
63	0.7254	6.04	7.26	45.19	364.93	8.689	1.381	8.828	308.75	5.978	63
64	0.7216	6.01	7.22	44.96	366.82	8.734	1.389	8.874	310.35	6.009	64
65	0.7179	5.98	7.18	44.73	368.71	8.779	1.396	8.920	311.95	6.040	65
66	0.7143	5.95	7.14	44.50	370.60	8.824	1.403	8.966	313.55	6.071	66
67	0.7107	5.92	7.11	44.27	372.50	8.869	1.410	9.011	315.15	6.102	67
68	0.7071	5.89	7.07	44.05	374.39	8.914	1.417	9.057	316.75	6.132	68
69	0.7035	5.86	7.04	43.83	376.28	8.959	1.424	9.103	318.35	6.163	69
70	0.7000	5.83	7.00	43.61	378.17	9.004	1.432	9.148	319.95	6.194	70
71	0.6965	5.80	6.97	43.39	380.06	9.049	1.439	9.194	321.55	6.225	71
72	0.6931	5.77	6.93	43.18	381.95	9.094	1.446	9.240	323.15	6.256	72
73	0.6897	5.74	6.90	42.97	383.84	9.139	1.453	9.286	324.75	6.287	73
74	0.6863	5.72	6.86	42.75	385.73	9.184	1.460	9.331	326.35	6.318	74
75	0.6829	5.69	6.83	42.55	387.62	9.229	1.467	9.377	327.94	6.349	75
76	0.6796	5.66	6.80	42.34	389.51	9.274	1.474	9.423	329.54	6.380	76
77	0.6763	5.63	6.76	42.13	391.40	9.319	1.482	9.469	331.14	6.411	77
78	0.6731	5.61	6.73	41.93	393.29	9.364	1.489	9.514	332.74	6.442	78
79	0.6699	5.58	6.70	41.73	395.19	9.409	1.496	9.560	334.34	6.473	79
80	0.6667	5.55	6.67	41.53	397.08	9.454	1.503	9.606	335.94	6.504	80
81	0.6635	5.53	6.64	41.34	398.97	9.499	1.510	9.652	337.54	6.535	81
82	0.6604	5.50	6.60	41.14	400.86	9.544	1.517	9.697	339.14	6.566	82
83	0.6573	5.47	6.57	40.95	402.75	9.589	1.525	9.743	340.74	6.597	83
84	0.6542	5.45	6.54	40.76	404.64	9.634	1.532	9.789	342.34	6.628	84
85	0.6512	5.42	6.51	40.57	406.53	9.679	1.539	9.835	343.94	6.659	85
86	0.6481	5.40	6.48	40.38	408.42	9.724	1.546	9.880	345.54	6.690	86
87	0.6452	5.37	6.45	40.19	410.31	9.769	1.553	9.926	347.14	6.721	87
88	0.6422	5.35	6.42	40.01	412.20	9.814	1.560	9.972	348.74	6.752	88
89	0.6393	5.32	6.39	39.83	414.09	9.859	1.568	10.018	350.34	6.783	89
90	0.6364	5.30	6.36	39.64	415.99	9.904	1.575	10.063	351.94	6.814	90

Temperature Corrections to Readings of Specific Gravity Hydrometers in American Petroleum Oils at Various Temperatures

(Standard at 60°/60° F.)

Observed temperature, ° F.	Observed Specific Gravity						
	0.650	0.700	0.750	0.800	0.850	0.900	0.950
	Subtract from Observed Specific Gravity						
30	0.016	0.015	0.014	0.012	0.011	0.011	0.011
32	0.015	0.014	0.013	0.012	0.011	0.010	0.010
34	0.014	0.013	0.012	0.011	0.010	0.010	0.010
36	0.013	0.012	0.011	0.010	0.009	0.009	0.009
38	0.012	0.011	0.010	0.009	0.008	0.008	0.008
40	0.0195	0.0095	0.0090	0.0080	0.0075	0.0070	0.0070
42	0.0095	0.0085	0.0080	0.0070	0.0065	0.0065	0.0065
44	0.0085	0.0075	0.0070	0.0065	0.0060	0.0060	0.0055
46	0.0075	0.0065	0.0060	0.0055	0.0050	0.0050	0.0050
48	0.0065	0.0060	0.0055	0.0050	0.0045	0.0045	0.0040
50	0.0050	0.0050	0.0045	0.0040	0.0035	0.0035	0.0035
52	0.0040	0.0040	0.0035	0.0030	0.0030	0.0030	0.0030
54	0.0030	0.0030	0.0025	0.0025	0.0020	0.0020	0.0020
56	0.0020	0.0020	0.0020	0.0015	0.0015	0.0015	0.0015
58	0.0010	0.0010	0.0010	0.0005	0.0005	0.0005	0.0005
	Add to Observed Specific Gravity						
60	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
62	0.0010	0.0010	0.0010	0.0005	0.0005	0.0005	
64	0.0020	0.0020	0.0015	0.0015	0.0015	0.0015	
66	0.0030	0.0030	0.0025	0.0025	0.0020	0.0020	
68	0.0040	0.0040	0.0035	0.0030	0.0030	0.0030	
70	0.0050	0.0050	0.0045	0.0040	0.0040	0.0035	
72	0.0060	0.0055	0.0050	0.0045	0.0045	0.0040	
74	0.0070	0.0065	0.0060	0.0055	0.0050	0.0050	
76	0.0080	0.0075	0.0070	0.0065	0.0060	0.0055	
78	0.0090	0.0085	0.0080	0.0070	0.0065	0.0065	
80	0.010	0.009	0.008	0.008	0.007	0.007	
82	0.011	0.010	0.009	0.008	0.008	0.007	
84	0.012	0.011	0.010	0.009	0.009	0.008	
86	0.013	0.012	0.011	0.010	0.009	0.009	
88	0.014	0.013	0.012	0.011	0.010	0.010	
90	0.015	0.014	0.013	0.012	0.011	0.010	
92	0.016	0.015	0.013	0.012	0.011	0.011	
94	0.017	0.016	0.014	0.013	0.012	0.012	
96	0.018	0.016	0.015	0.014	0.013	0.013	
98	0.019	0.017	0.016	0.015	0.014	0.013	
100	0.020	0.018	0.017	0.015	0.014	0.014	
102	0.021	0.019	0.018	0.016	0.015	0.015	
104	0.022	0.020	0.018	0.017	0.016	0.015	
106	0.023	0.021	0.019	0.017	0.016	0.016	
108	0.024	0.022	0.020	0.018	0.017	0.017	
110	0.025	0.023	0.021	0.019	0.018	0.017	
112	0.026	0.024	0.022	0.020	0.019	0.018	
114	0.027	0.025	0.022	0.020	0.019	0.019	
116	0.028	0.026	0.023	0.021	0.020	0.019	
118	0.029	0.026	0.024	0.022	0.021	0.020	
120	0.030	0.027	0.025	0.023	0.022	0.021	

(This table is calculated from the same data as Table I, Circular No. 57, Bureau of Standards).

Temperature Corrections to Readings of Baumé Hydrometers in American Petroleum Oils at Various Temperatures

(Standard at 60° F.; modulus 140)

Observed temperature, ° F.	Observed Degrees Baumé							
	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
	Add to Observed Degrees Baumé							
30	1.7	2.0	2.4	3.0	3.7	4.3	5.0	5.7
32	1.6	1.9	2.3	2.8	3.4	4.0	4.7	5.3
34	1.5	1.8	2.1	2.6	3.1	3.7	4.3	4.9
36	1.4	1.6	2.0	2.4	2.9	3.4	4.0	4.6
38	1.3	1.5	1.8	2.2	2.6	3.1	3.6	4.2
40	1.2	1.4	1.6	2.0	2.4	2.8	3.2	3.8
42	1.1	1.2	1.5	1.8	2.2	2.5	2.9	3.4
44	0.9	1.1	1.3	1.6	2.0	2.2	2.6	3.0
46	0.8	0.9	1.1	1.4	1.7	1.9	2.3	2.7
48	0.7	0.8	0.9	1.2	1.4	1.6	2.0	2.3
50	0.6	0.7	0.8	1.0	1.2	1.4	1.6	1.9
52	0.5	0.6	0.7	0.8	1.0	1.1	1.3	1.5
54	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.1
56	0.2	0.3	0.3	0.4	0.5	0.6	0.6	0.7
58	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.4
	Subtract from Observed Degrees Baumé							
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4
64	0.2	0.3	0.3	0.4	0.4	0.6	0.6	0.7
66	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
68	0.5	0.6	0.6	0.7	0.9	1.1	1.3	1.4
70	0.6	0.7	0.8	0.9	1.1	1.4	1.6	1.7
72	0.7	0.8	0.9	1.1	1.3	1.6	1.9	2.1
74	0.8	0.9	1.1	1.3	1.6	1.8	2.2	2.5
76	0.9	1.1	1.3	1.5	1.8	2.1	2.5	2.8
78	1.0	1.2	1.4	1.7	2.0	2.4	2.8	3.1
80	1.1	1.3	1.5	1.8	2.2	2.6	3.1	3.5
82	1.2	1.4	1.7	2.0	2.5	2.9	3.4	3.9
84	1.3	1.5	1.8	2.2	2.7	3.2	3.7	4.3
86	1.4	1.7	2.0	2.4	2.9	3.4	4.0	4.6
88	1.6	1.8	2.1	2.6	3.1	3.7	4.2	4.9
90	1.7	2.0	2.3	2.7	3.3	3.9	4.5	5.2
92	1.8	2.1	2.4	2.9	3.5	4.2	4.8	5.6
94	1.9	2.2	2.6	3.1	3.8	4.4	5.1	5.9
96	2.0	2.3	2.7	3.3	4.0	4.6	5.4	6.3
98	2.1	2.4	2.9	3.4	4.2	4.9	5.7	6.6
100	2.2	2.6	3.0	3.6	4.4	5.1	6.0	6.9
102	2.3	2.7	3.2	3.8	4.6	5.4	6.3	7.2
104	2.4	2.9	3.3	4.0	4.8	5.7	6.6	7.5
106	2.5	3.0	3.5	4.2	5.0	5.9	6.9	7.9
108	2.7	3.1	3.6	4.3	5.2	6.2	7.2	8.2
110	2.8	3.2	3.7	4.4	5.4	6.4	7.5	8.5
112	2.9	3.3	3.9	4.6	5.6	6.7	7.7	8.8
114	3.0	3.4	4.0	4.7	5.8	6.9	7.9	9.1
116	3.1	3.6	4.1	4.9	6.0	7.1	8.2	9.4
118	3.2	3.7	4.3	5.1	6.2	7.3	8.5	9.8
120	3.3	3.8	4.4	5.3	6.4	7.5	8.8	10.1

(This table is calculated from the same data as Table II, Circular No. 57, Bureau of Standards.)

Temperature Corrections to Apparent Specific Gravities of Petroleum Oils

[This table gives the correction to be added to apparent specific gravities of heavy petroleum oils (fuel oils, lubricating oils, etc.), at temperatures from 60° to 210° F. to give the true specific gravity of the oil at 60°/60° F. It is assumed that the hydrometer or picnometer used is of glass having a coefficient of cubical expansion of 0.000023 per degree Centigrade and is correct at 60° F.]

Observed temperature, ° F.	Observed Specific Gravity											
	0.850	0.860	0.870	0.880	0.890	0.900	0.910	0.920	0.930	0.940	0.950	0.960
	Add to Observed Specific Gravity to give True Specific Gravity at 60°/60° F.											
60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
62	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
64	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
66	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
68	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
70	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
72	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
74	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
76	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
78	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
80	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
82	0.008	0.008	0.008	0.008	0.008	0.007	0.007	0.007	0.007	0.007	0.007	0.007
84	0.009	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
86	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
88	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
90	0.011	0.011	0.011	0.011	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
92	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
94	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
96	0.013	0.013	0.013	0.013	0.013	0.013	0.012	0.012	0.012	0.012	0.012	0.012
98	0.014	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
100	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
105	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
110	0.018	0.018	0.018	0.018	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
115	0.020	0.020	0.020	0.020	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
120	0.022	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
125	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.022	0.022	
130	0.025	0.025	0.025	0.025	0.025	0.024	0.024	0.024	0.024	0.024	0.024	
135	0.027	0.027	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	
140	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.027	0.027	
145	0.030	0.030	0.030	0.030	0.030	0.030	0.029	0.029	0.029	0.029	0.029	
150	0.032	0.032	0.032	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	
155	0.034	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033		
160	0.035	0.035	0.035	0.035	0.035	0.035	0.034	0.034	0.034	0.034		
165	0.037	0.037	0.037	0.037	0.036	0.036	0.036	0.036	0.036	0.036		
170	0.039	0.039	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.037		
175	0.040	0.040	0.040	0.040	0.040	0.040	0.039	0.039	0.039	0.039		
180	0.042	0.042	0.042	0.041	0.041	0.041	0.041	0.041	0.041	0.041		
185	0.044	0.044	0.043	0.043	0.043	0.043	0.043	0.043	0.042			
190	0.045	0.045	0.045	0.045	0.045	0.044	0.044	0.044	0.044			
195	0.047	0.047	0.047	0.047	0.046	0.046	0.046	0.046	0.046			
200	0.049	0.049	0.048	0.048	0.048	0.048	0.048	0.048	0.047			
205	0.051	0.050	0.050	0.050	0.050	0.050	0.049	0.049	0.049			
210	0.052	0.052	0.052	0.051	0.051	0.051	0.051	0.051	0.051			

(For more complete oil tables, see Circular No. 57, Bureau of Standards.)

Temperature Corrections to Apparent Degrees Baumé of Petroleum Oils

[This table gives the corrections to be subtracted from the apparent degrees Baumé of heavy petroleum oils (fuel oils, lubricating oils, etc.) at temperatures from 60° to 210° F. to give the true degrees Baumé at 60° F. (modulus, 140). It is assumed that the hydrometer is of glass having a coefficient of cubical expansion of 0.000023 per degree Centigrade and is correct at 60° F.]

Observed temperature, ° F.	Observed Degrees Baumé											
	14	16	18	20	22	24	26	28	30	32	34	36
	Subtract from Observed Degrees Baumé to give True Degrees Baumé at 60° F.											
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
64	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
66	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
68	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
70	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.8	0.8
72	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.9	0.9
74	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.1
76	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2
78	0.9	0.9	0.9	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.4
80	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.5
82	...	1.1	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.6
84	...	1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.5	1.6	1.7	1.8
86	...	1.4	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.8	1.8	1.9
88	...	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	2.0	2.0
90	...	1.6	1.6	1.7	1.7	1.8	1.8	1.9	2.0	2.0	2.1	2.1
92	...	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.3
94	...	1.8	1.8	1.9	1.9	2.0	2.0	2.1	2.2	2.2	2.3	2.4
96	...	1.9	1.9	2.0	2.0	2.1	2.2	2.3	2.3	2.4	2.5	2.5
98	...	2.0	2.0	2.1	2.2	2.2	2.3	2.4	2.4	2.5	2.6	2.7
100	...	2.1	2.2	2.2	2.3	2.3	2.4	2.5	2.6	2.7	2.7	2.8
105	...	2.4	2.4	2.5	2.6	2.6	2.7	2.8	2.9	3.0	3.1	3.2
110	...	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5
115	...	2.9	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.8	3.9
120	...	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.2
125	...	...	3.4	3.5	3.6	3.7	3.8	4.0	4.1	4.2	4.3	4.5
130	...	...	3.7	3.8	3.9	4.0	4.1	4.3	4.4	4.5	4.7	4.8
135	...	...	3.9	4.1	4.2	4.3	4.4	4.6	4.7	4.8	5.0	5.2
140	...	...	4.2	4.3	4.4	4.6	4.7	4.8	5.0	5.1	5.3	5.5
145	...	...	4.4	4.6	4.7	4.8	5.0	5.1	5.3	5.4	5.6	5.8
150	...	...	4.7	4.8	5.0	5.1	5.2	5.4	5.6	5.7	5.9	6.1
155	...	...	4.9	5.1	5.2	5.4	5.5	5.7	5.9	6.0	6.2	6.4
160	...	...	...	5.3	5.5	5.6	5.8	6.0	6.2	6.3	6.5	6.7
165	...	...	...	5.6	5.7	5.9	6.1	6.3	6.5	6.6	6.8	7.0
170	...	...	...	5.8	6.0	6.2	6.3	6.5	6.7	6.9	7.1	7.3
175	...	...	...	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6
180	...	...	...	6.3	6.5	6.6	6.8	7.1	7.3	7.5	7.7	8.0
185	...	...	...	6.5	6.7	6.9	7.1	7.3	7.6	7.8	8.0	8.3
190	...	...	...	6.8	7.0	7.2	7.4	7.6	7.8	8.1	8.3	8.6
195	...	...	...	7.0	7.2	7.4	7.6	7.9	8.1	8.4	8.6	8.9
200	...	...	...	...	7.5	7.7	7.9	8.1	8.4	8.6	8.9	9.2
205	...	...	...	...	7.7	7.9	8.2	8.4	8.7	8.9	9.2	9.5
210	...	...	...	...	8.0	8.2	8.4	8.7	8.9	9.2	9.5	9.8

(For more complete oil tables, see Circular No. 57, Bureau of Standards.)

SATURATED AMMONIA VAPOR; PRESSURE AND CORRESPONDING TEMPERATURE

These values are figured from the tables by Goodenough and Mosher, Bulletin No. 66, University of Illinois. The temperatures are given to the nearest 0.5° F.

Pressure, pounds gage	Temperature, ° F.	Pressure, pounds gage	Temperature, ° F.	Pressure, pounds gage	Temperature, ° F.	Pressure, pounds gage	Temperature, ° F.
0	−27	50	34	100	63.5	200	100.5
1	−24	51	35	102	64.5	202	101
2	−22	52	36	104	65.5	204	101.5
3	−20	53	36.5	106	66.5	206	102
4	−18	54	37	108	67	208	102.5
5	−16	55	38	110	68	210	103
6	−14	56	38.5	112	69	212	103.5
7	−12	57	39	114	70	214	104.5
8	−10.5	58	40	116	71	216	105
9	− 9	59	40.5	118	71.5	218	105.5
10	− 7	60	41	120	72.5	220	106
11	− 5.5	61	42	122	73.5	222	106.5
12	− 4	62	42.5	124	74	224	107
13	− 2.5	63	43	126	75	226	107.5
14	− 1	64	44	128	76	228	108
15	0	65	44.5	130	76.5	230	108.5
16	+ 1	66	45	132	77.5	232	109.5
17	2.5	67	46	134	78	234	110
18	4	68	46.5	136	79	236	110.5
19	5	69	47	138	79.5	238	111
20	6.5	70	47.5	140	80.5	240	111.5
21	7.5	71	48	142	81	242	112
22	9	72	49	144	82	244	112.5
23	10	73	49.5	146	82.5	246	113
24	11	74	50	148	83.5	248	113.5
25	12	75	50.5	150	84	250	114
26	13	76	51	152	85	252	114.5
27	14	77	51.5	154	85.5	254	115
28	15	78	52	156	86.5	256	115.5
29	16	79	53	158	87	258	116
30	17	80	53.5	160	87.5	260	116.5
31	18	81	54	162	88.5	262	117
32	19	82	54.5	164	89	264	117.5
33	20	83	55	166	89.5	266	118
34	21	84	55.5	168	90.5	268	118.5
35	22	85	56	170	91	270	119.
36	23	86	56.5	172	91.5	272	119.5
37	24	87	57	174	92.5	274	120
38	25	88	57.5	176	93	276	120.5
39	25.5	89	58	178	93.5	278	120.5
40	26.5	90	58.5	180	94.5	280	121
41	27	91	59	182	95	282	121.5
42	28	92	59.5	184	95.5	284	122
43	29	93	60	186	96	286	122.5
44	30	94	60.5	188	96.5	288	123
45	30.5	95	61	190	97.5	290	123.5
46	31	96	61.5	192	98	292	124.
47	32	97	62	194	98.5	294	124.5
48	33	98	62.5	196	99	296	124.5
49	33.5	99	63	198	99.5	298	125
						300	125.5

AQUA AMMONIA

By W. C. Ferguson

Degrees Baumé	Specific gravity, 60°/60° F.	Per cent NH_3	Degrees Baumé	Specific gravity, 60°/60° F.	Per cent NH_3	Degrees Baumé	Specific gravity, 60°/60° F.	Per cent NH_3
10.00	1.0000	0.00	16.25	0.9573	10.73	22.50	0.9180	22.56
10.25	0.9982	0.40	16.50	0.9556	11.18	22.75	0.9165	23.04
10.50	0.9964	0.80	16.75	0.9540	11.64	23.00	0.9150	23.52
10.75	0.9947	1.21	17.00	0.9524	12.10	23.25	0.9135	24.01
11.00	0.9929	1.62	17.25	0.9508	12.56	23.50	0.9121	24.50
11.25	0.9912	2.04	17.50	0.9492	13.02	23.75	0.9106	24.99
11.50	0.9894	2.46	17.75	0.9475	13.49	24.00	0.9091	25.48
11.75	0.9876	2.88	18.00	0.9459	13.96	24.25	0.9076	25.97
12.00	0.9859	3.30	18.25	0.9444	14.43	24.50	0.9061	26.46
12.25	0.9842	3.73	18.50	0.9428	14.90	24.75	0.9047	26.95
12.50	0.9825	4.16	18.75	0.9412	15.37	25.00	0.9032	27.44
12.75	0.9807	4.59	19.00	0.9396	15.84	25.25	0.9018	27.93
13.00	0.9790	5.02	19.25	0.9380	16.32	25.50	0.9003	28.42
13.25	0.9773	5.45	19.50	0.9365	16.80	25.75	0.8989	28.91
13.50	0.9756	5.88	19.75	0.9349	17.28	26.00	0.8974	29.40
13.75	0.9739	6.31	20.00	0.9333	17.76	26.25	0.8960	29.89
14.00	0.9722	6.74	20.25	0.9318	18.24	26.50	0.8946	30.38
14.25	0.9705	7.17	20.50	0.9302	18.72	26.75	0.8931	30.87
14.50	0.9689	7.61	20.75	0.9287	19.20	27.00	0.8917	31.36
14.75	0.9672	8.05	21.00	0.9272	19.68	27.25	0.8903	31.85
15.00	0.9655	8.49	21.25	0.9256	20.16	27.50	0.8889	32.34
15.25	0.9639	8.93	21.50	0.9241	20.64	27.75	0.8875	32.83
15.50	0.9622	9.38	21.75	0.9226	21.12	28.00	0.8861	33.32
15.75	0.9605	9.83	22.00	0.9211	21.60	28.25	0.8847	33.81
16.00	0.9589	10.28	22.25	0.9195	22.08	28.50	0.8833	34.30
						28.75	0.8819	34.79
						29.00	0.8805	35.28

Ammonia—Allowance for Temperature

As the coefficient of expansion for ammonia solutions varies with the temperature, correction must be applied according to the following table:

Degrees Baumé	Corrections to be Added for Each Degree below 60° F.		Corrections to be Subtracted for Each Degree above 60° F.			
	40° F.	50° F.	70° F.	80° F.	90° F.	100° F.
14	0.015	0.017	0.020	0.022	0.024	0.026
16	0.021	0.023	0.026	0.028	0.030	0.032
18	0.027	0.029	0.031	0.033	0.035	0.037
20	0.033	0.036	0.037	0.038	0.040	0.042
22	0.039	0.042	0.043	0.045	0.047	
26	0.053	0.057	0.057	0.059		

Sulphuric Acid

By W. C. Ferguson and H. P. Talbot

Degrees Baumé	Specific gravity, 60°/60° F.	Per cent H_2SO_4	Degrees Baumé	Specific gravity, 60°/60° F.	Per cent H_2SO_4	Degrees Baumé	Specific gravity, 60°/60° F.	Per cent H_2SO_4
0	1.0000	0.00	25	1.2083	28.28	50	1.5263	62.18
1	1.0069	1.02	26	1.2185	29.53	51	1.5462	63.66
2	1.0140	2.08	27	1.2288	30.79	52	1.5591	65.13
3	1.0211	3.13	28	1.2393	32.05	53	1.5761	66.63
4	1.0284	4.21	29	1.2500	33.33	54	1.5934	68.13
5	1.0357	5.28	30	1.2609	34.63	55	1.6111	69.65
6	1.0432	6.37	31	1.2719	35.93	56	1.6292	71.17
7	1.0507	7.45	32	1.2832	37.26	57	1.6477	72.75
8	1.0584	8.55	33	1.2946	38.58	58	1.6667	74.36
9	1.0662	9.66	34	1.3063	39.92	59	1.6860	75.99
10	1.0741	10.77	35	1.3182	41.27	60	1.7059	77.67
11	1.0821	11.89	36	1.3303	42.63	61	1.7262	79.43
12	1.0902	13.01	37	1.3426	43.99	62	1.7470	81.30
13	1.0985	14.13	38	1.3551	45.35	63	1.7683	83.34
14	1.1069	15.25	39	1.3679	46.72	64	1.7901	85.66
15	1.1154	16.38	40	1.3810	48.10	64¼	1.7957	86.33
16	1.1240	17.53	41	1.3942	49.47	64½	1.8012	87.04
17	1.1328	18.71	42	1.4078	50.87	64¾	1.8068	87.81
18	1.1417	19.89	43	1.4216	52.26	65	1.8125	88.65
19	1.1508	21.07	44	1.4356	53.66	65¼	1.8181	89.55
20	1.1600	22.25	45	1.4500	55.07	65½	1.8239	90.60
21	1.1694	23.43	46	1.4646	56.48	65¾	1.8297	91.80
22	1.1789	24.61	47	1.4796	57.90	66	1.8354	93.19
23	1.1885	25.81	48	1.4948	59.32			
24	1.1983	27.03	49	1.5104	60.75			

Specific gravity determinations were made at 60° F., compared with water at 60° F.

From the specific gravities the corresponding degrees Baumé were calculated by the following formula:

$$°\text{ Baumé} = 145 - \frac{145}{\text{specific gravity } \frac{60°}{60°}\text{ F.}}.$$

Allowance for Temperatures

At 10° Baumé correction of 0.029° Baumé or 0.00023 specific gravity for every 1° F.
At 20° Baumé correction of 0.036° Baumé or 0.00034 specific gravity for every 1° F.
At 30° Baumé correction of 0.035° Baumé or 0.00039 specific gravity for every 1° F.
At 40° Baumé correction of 0.031° Baumé or 0.00041 specific gravity for every 1° F.
At 50° Baumé correction of 0.028° Baumé or 0.00045 specific gravity for every 1° F.
At 60° Baumé correction of 0.026° Baumé or 0.00053 specific gravity for every 1° F.
At 63° Baumé correction of 0.026° Baumé or 0.00057 specific gravity for every 1° F.
At 66° Baumé correction of 0.0235° Baumé or 0.00054 specific gravity for every 1° F.

For temperatures above 60° F., the correction is added to the observed indication; below 60° F. it is subtracted.

The tables were approved and adopted as standards by the Manufacturing Chemists' Association of the United States, June 23, 1904.

SPECIFIC GRAVITY AND CONTENT OF SULPHURIC ACID

Specific gravity, $\frac{15°}{4°}$ in vacuo	100 Parts by Weight Correspond to: Per cent SO_3	100 Parts by Weight Correspond to: Per cent H_2SO_4	1 Liter Contains Grams: SO_3	1 Liter Contains Grams: H_2SO_4	Specific gravity, $\frac{15°}{4°}$ in vacuo	100 Parts by Weight Correspond to: Per cent SO_3	100 Parts by Weight Correspond to: Per cnet H_2SO_4	1 Liter Contains Grams: SO_3	1 Liter Contains Grams: H_2SO_4
1.000	0.07	0.09	1	1	1.175	19.69	24.12	231	283
1.005	0.68	0.83	7	8	1.180	20.21	24.76	238	292
1.010	1.28	1.57	13	16	1.185	20.73	25.40	246	301
1.015	1.88	2.30	19	23	1.190	21.26	26.04	253	310
1.020	2.47	3.03	25	31	1.195	21.78	26.68	260	319
1.025	3.07	3.76	32	39	1.200	22.30	27.32	268	328
1.030	3.67	4.49	38	46	1.205	22.82	27.95	275	337
1.035	4.27	5.23	44	54	1.210	23.33	28.58	282	346
1.040	4.87	5.96	51	62	1.215	23.84	29.21	290	355
1.045	5.45	6.67	57	71	1.220	24.36	29.84	297	364
1.050	6.02	7.37	63	77	1.225	24.88	30.48	305	373
1.055	6.59	8.07	70	85	1.230	25.39	31.11	312	382
1.060	7.16	8.77	76	93	1.235	25.88	31.70	320	391
1.065	7.73	9.47	82	102	1.240	26.35	32.28	327	400
1.070	8.32	10.19	89	109	1.245	26.83	32.86	334	409
1.075	8.90	10.90	96	117	1.250	27.29	33.43	341	418
1.080	9.47	11.60	103	125	1.255	27.76	34.00	348	426
1.085	10.04	12.30	109	133	1.260	28.22	34.57	356	435
1.090	10.60	12.99	116	142	1.265	28.69	35.14	363	444
1.095	11.16	13.67	122	150	1.270	29.15	35.71	370	454
1.100	11.71	14.35	129	158	1.275	29.62	36.29	377	462
1.105	12.27	15.03	136	166	1.280	30.10	36.87	385	472
1.110	12.82	15.71	143	175	1.285	30.57	37.45	393	481
1.115	13.36	16.36	149	183	1.290	31.04	38.03	400	490
1.120	13.89	17.01	156	191	1.295	31.52	38.61	408	500
1.125	14.42	17.66	162	199	1.300	31.99	39.19	416	510
1.130	14.95	18.31	169	207	1.305	32.46	39.77	424	519
1.135	15.48	18.96	176	215	1.310	32.94	40.35	432	529
1.140	16.01	19.61	183	223	1.315	33.41	40.93	439	538
1.145	16.54	20.26	189	231	1.320	33.88	41.50	447	548
1.150	17.07	20.91	196	239	1.325	34.35	42.08	455	557
1.155	17.59	21.55	203	248	1.330	34.80	42.66	462	567
1.160	18.11	22.19	210	257	1.335	35.27	43.20	471	577
1.165	18.64	22.83	217	266	1.340	35.71	43.74	479	586
1.170	19.16	23.47	224	275	1.345	36.14	44.28	486	596

Specific Gravity and Content of Sulphuric Acid—*Continued*

Specific gravity, $\frac{15^\circ}{4^\circ}$ in vacuo	100 Parts by Weight correspond to		1 Liter Contains Grams		Specific gravity, $\frac{15^\circ}{4^\circ}$ in vacuo	100 Parts by Weight correspond to		1 Liter Contains Grams	
	Per cent SO_3	Per cent H_2SO_4	SO_3	H_2SO_4		Per cent SO_3	Per cent H_2SO_4	SO_3	H_2SO_4
1.350	36.58	44.82	494	605	1.525	50.66	62.06	773	946
1.355	37.02	45.35	502	614	1.530	51.04	62.53	781	957
1.360	37.45	45.88	509	624	1.535	51.43	63.00	789	967
1.365	37.89	46.41	517	633	1.540	51.78	63.43	797	977
1.370	38.32	46.94	525	643	1.545	52.12	63.85	805	987
1.375	38.75	47.47	533	653	1.550	52.46	64.26	813	996
1.380	39.18	48.00	541	662	1.555	52.79	64.67	821	1006
1.385	39.62	48.53	549	672	1.560	53.12	65.08	829	1015
1.390	40.05	49.06	557	682	1.565	53.46	65.49	837	1025
1.395	40.48	49.50	564	692	1.570	53.80	65.90	845	1035
1.400	40.91	50.11	573	702	1.575	54.13	66.30	853	1044
1.405	41.33	50.63	581	711	1.580	54.46	66.71	861	1054
1.410	41.76	51.15	589	721	1.585	54.80	67.13	869	1064
1.415	42.17	51.66	597	730	1.590	55.18	67.59	877	1075
1.420	42.57	52.15	604	740	1.595	55.55	68.05	886	1085
1.425	42.96	52.63	612	750	1.600	55.93	68.51	897	1096
1.430	43.36	53.11	620	759	1.605	56.30	68.97	904	1107
1.435	43.75	53.59	628	769	1.610	56.68	69.43	913	1118
1.440	44.14	54.07	636	779	1.615	57.05	69.89	921	1128
1.445	44.53	54.55	643	789	1.620	57.40	70.32	930	1139
1.450	44.92	55.03	651	798	1.625	57.75	70.74	938	1150
1.455	45.31	55.50	659	808	1.630	58.09	71.16	947	1160
1.460	45.69	55.97	667	817	1.635	58.43	71.57	955	1170
1.465	46.07	56.43	675	827	1.640	58.77	71.99	964	1181
1.470	46.45	56.90	683	837	1.645	59.10	72.40	972	1192
1.475	46.83	57.37	691	846	1.650	59.45	72.82	981	1202
1.480	47.21	57.83	699	856	1.655	59.78	73.23	989	1212
1.485	47.57	58.28	707	865	1.660	60.11	73.64	998	1222
1.490	47.95	58.74	715	876	1.665	60.46	74.07	1007	1233
1.495	48.34	59.22	723	885	1.670	60.82	74.51	1016	1244
1.500	48.73	59.70	731	896	1.675	61.20	74.97	1025	1256
1.505	49.12	60.18	739	906	1.680	61.57	75.42	1034	1267
1.510	49.51	60.65	748	916	1.685	61.93	75.86	1043	1278
1.515	49.89	61.12	756	926	1.690	62.29	76.30	1053	1289
1.520	50.28	61.59	764	936	1.695	62.64	76.73	1062	1301

SPECIFIC GRAVITY AND CONTENT OF SULPHURIC ACID—*Continued*

Specific gravity, $\frac{15°}{4°}$ in vacuo	100 Parts by Weight Correspond to		1 Liter Contains Grams		Specific gravity, $\frac{15°}{4°}$ in vacuo	100 Parts by Weight Correspond to		1 Liter Contains Grams	
	Per cent SO_3	Per cent H_2SO_4	SO_3	H_2SO_4		Per cent SO_3	Per cent H_2SO_4	SO_3	H_2SO_4
1.700	63.00	77.17	1071	1312	1.823	73.96	90.60	1348	1651
1.705	63.35	77.60	1080	1323	1.824	74.12	90.80	1352	1656
1.710	63.70	78.04	1089	1334	1.825	74.29	91.00	1356	1661
1.715	64.07	78.48	1099	1346	1.826	74.49	91.25	1360	1666
1.720	64.43	78.92	1108	1357	1.827	74.69	91.50	1364	1671
1.725	64.78	79.36	1118	1369	1.828	74.86	91.70	1368	1676
1.730	65.14	79.80	1127	1381	1.829	75.03	91.90	1372	1681
1.735	65.50	80.24	1136	1392	1.830	75.19	92.10	1376	1685
1.740	65.86	80.68	1146	1404	1.831	75.35	92.30	1380	1690
1.745	66.22	81.12	1156	1416	1.832	75.53	92.52	1384	1695
1.750	66.58	81.56	1165	1427	1.833	75.72	92.75	1388	1700
1.755	66.94	82.00	1175	1439	1.834	75.96	93.05	1393	1706
1.760	67.30	82.44	1185	1451	1.835	76.27	93.43	1400	1713
1.765	67.65	82.88	1194	1463	1.836	76.57	93.80	1405	1722
1.770	68.02	83.32	1204	1475	1.837	76.90	94.20	1412	1730
1.775	68.49	83.90	1216	1489	1.838	77.23	94.60	1419	1739
1.780	68.98	84.50	1228	1504	1.839	77.55	95.00	1426	1748
1.785	69.47	85.10	1240	1519	1.840	78.04	95.60	1436	1759
1.790	69.96	85.70	1252	1534	1.8405	78.33	95.95	1441	1765
1.795	70.46	86.30	1265	1549	1.8410	79.19	97.00	1458	1786
1.800	70.94	86.90	1277	1564	1.8415	79.76	97.70	1469	1799
1.805	71.50	87.60	1291	1581	1.8410	80.16	98.20	1476	1808
1.810	72.08	88.30	1305	1598	1.8405	80.57	98.70	1483	1816
1.815	72.69	89.05	1319	1621	1.8400	80.98	99.20	1490	1825
1.820	73.51	90.05	1338	1639	1.8395	81.18	99.45	1494	1830
1.821	73.63	90.20	1341	1643	1.8390	81.39	99.70	1497	1834
1.822	73.80	90.40	1345	1647	1.8385	81.59	99.95	1500	1838

PERCENTAGE OF SULPHUR TRIOXIDE AND SULPHURIC ACID IN FUMING SULPHURIC ACID

Total SO_3 as found by titration	The Acid Contains		Total SO_3 as found by titration	The Acid Contains		Total SO_3 as found by titration	The Acid Contains	
	Per cent H_2SO_4	Per cent SO_3		Per cent H_2SO_4	Per cent SO_3		Per cent H_2SO_4	Per cent SO_3
81.8326	100	0	87.8775	66	34	93.9389	33	67
81.8163	99	1	88.0612	65	35	94.1224	32	68
82.0000	98	2	88.2448	64	36	94.3061	31	69
82.1836	97	3	88.4285	63	37	94.4897	30	70
82.3674	96	4	88.6122	62	38	94.6734	29	71
82.5510	95	5	88.7959	61	39	94.8571	28	72
82.7346	94	6	88.9795	60	40	95.0408	27	73
82.9183	93	7	89.1632	59	41	95.2244	26	74
83.1020	92	8	89.3469	58	42	95.4081	25	75
83.2857	91	9	89.5306	57	43	95.5918	24	76
83.4693	90	10	89.7142	56	44	95.7755	23	77
83.6530	89	11	89.8979	55	45	95.9591	22	78
83.8367	88	12	90.0816	54	46	96.1428	21	79
84.0204	87	13	90.2653	53	47	96.3265	20	80
84.2040	86	14	90.4489	52	48	96.5102	19	81
84.3877	85	15	90.6326	51	49	96.6938	18	82
84.5714	84	16	90.8163	50	50	96.8775	17	83
84.7551	83	17	91.0000	49	51	97.0612	16	84
84.9387	82	18	91.1836	48	52	97.2448	15	85
85.1224	81	19	91.3673	47	53	97.4285	14	86
85.3061	80	20	91.5510	46	54	97.6122	13	87
85.4897	79	21	91.7346	45	55	97.7959	12	88
85.6734	78	22	91.9183	44	56	97.9795	11	89
85.8571	77	23	92.1020	43	57	98.1632	10	90
86.0408	76	24	92.2857	42	58	98.3469	9	91
86.2244	75	25	92.4693	41	59	98.5306	8	92
86.4081	74	26	92.6530	40	60	98.7142	7	93
86.5918	73	27	92.8367	39	61	98.8979	6	94
86.7755	72	28	93.0204	38	62	99.0816	5	95
86.9591	71	29	93.2040	37	63	99.2753	4	96
87.1428	70	30	93.3877	36	64	99.4489	3	97
87.3265	69	31	93.5714	35	65	99.6326	2	98
87.5102	68	32	93.7551	34	66	99.8163	1	99
87.6938	67	33						

CONCENTRATION OF SODIUM HYDROXIDE SOLUTION AT 15° C.
(According to Lunge)

Specific gravity	Degrees Baumé	Degrees Twaddell	Per cent Na_2O	Per cent NaOH	1 Liter Contains Grams	
					Na_2O	NaOH
1.007	1.0	1.4	0.47	0.61	4	6
1.014	2.0	2.8	0.93	1.20	9	12
1.022	3.1	4.4	1.55	2.00	16	21
1.029	4.1	5.8	2.10	2.70	22	28
1.036	5.1	7.2	2.60	3.35	27	35
1.045	6.2	9.0	3.10	4.00	32	42
1.052	7.2	10.4	3.60	4.64	38	49
1.060	8.2	12.0	4.10	5.29	43	56
1.067	9.1	13.4	4.55	5.87	49	63
1.075	10.1	15.0	5.08	6.55	55	70
1.083	11.1	16.6	5.67	7.31	61	79
1.091	12.1	18.2	6.20	8.00	68	87
1.100	13.2	20.0	6.73	8.68	74	95
1.108	14.1	21.6	7.30	9.42	81	104
1.116	15.1	23.2	7.80	10.06	87	112
1.125	16.1	25.0	8.50	10.97	96	123
1.134	17.1	26.8	9.18	11.84	104	134
1.142	18.0	28.4	9.80	12.64	112	144
1.152	19.1	30.4	10.50	13.55	121	156
1.162	20.2	32.4	11.14	14.37	129	167
1.171	21.2	34.2	11.73	15.13	137	177
1.180	22.1	36.0	12.33	15.91	146	188
1.190	23.1	38.0	13.00	16.77	155	200
1.200	24.2	40.0	13.70	17.67	164	212
1.210	25.2	42.0	14.40	18.58	174	225
1.220	26.1	44.0	15.18	19.58	185	239
1.231	27.2	46.2	15.96	20.59	196	253
1.241	28.2	48.2	16.76	21.42	208	266
1.252	29.2	50.4	17.55	22.64	220	283
1.263	30.2	52.6	18.35	23.67	232	299
1.274	31.2	54.8	19.23	24.81	245	316
1.285	32.2	57.0	20.00	25.80	257	332
1.297	33.2	59.4	20.80	26.83	270	348
1.308	34.1	61.6	21.55	27.80	282	364
1.320	35.2	64.0	22.35	28.83	295	381
1.332	36.1	66.4	23.20	29.93	309	399
1.345	37.2	69.0	24.20	31.22	326	420
1.357	38.1	71.4	25.17	32.47	342	441
1.370	39.2	74.0	26.12	33.69	359	462
1.383	40.2	76.6	27.10	34.96	375	483
1.397	41.2	79.4	28.10	36.25	392	506
1.410	42.2	82.0	29.05	37.47	410	528
1.424	43.2	84.8	30.08	38.80	428	553
1.438	44.2	87.6	31.00	39.99	446	575
1.453	45.2	90.6	32.10	41.41	466	602
1.468	46.2	93.6	33.20	42.83	487	629
1.483	47.2	96.6	34.40	44.38	510	658
1.498	48.2	99.6	35.70	46.15	535	691
1.514	49.2	102.8	36.90	47.60	559	721
1.530	50.2	106.0	38.00	49.02	581	750

CALCIUM CHLORIDE ($CaCl_2$)

Degrees Baumé 60° F.	Specific gravity, 60°/60° F.	Degrees salometer, 60° F.	Per cent $CaCl_2$ by weight	Pounds $CaCl_2$ per gallon of solution (Approximate)	Freezing point, ° F.
0	1.000	0	0	0	+32
1	1.007	4	1	....	31.1
2.1	1.015	8	2	....	30.4
3.4	1.024	12	3	½	29.5
4.5	1.032	16	4	....	28.6
5.7	1.041	22	5	....	27.7
6.8	1.049	26	6	1	26.6
8	1.058	32	7	....	25.5
9.1	1.067	36	8	....	24.3
10.2	1.076	40	9	1½	22.8
11.4	1.085	44	10	....	21.3
12.5	1.094	48	11	....	19.7
13.5	1.103	52	12	2	18.1
14.6	1.112	58	13	....	16.3
15.6	1.121	62	14	....	14.3
16.8	1.131	68	15	2½	12.2
17.8	1.140	72	16	....	10
19	1.151	76	17	....	7.5
20	1.160	80	18	3	4.6
21	1.169	84	19	....	+ 1.7
22	1.179	88	20	....	− 1.4
23	1.188	92	21	3½	4.9
24	1.198	96	22	....	8.6
25	1.208	100	23	....	11.6
26	1.218	104	24	4	17.1
27	1.229	108	25	....	21.8
28	1.239	112	26	....	27
29	1.250	116	27	4½	32.6
30	1.261	120	28	....	39.2
31	1.272	124	29	....	46.2
32	1.283	128	30	5	−54.4

SODIUM CHLORIDE (NaCl)

(By Gerlock)

Specific gravity, 60°/60° F.	Degrees Baumé, 60° F.	Degrees salometer, 60° F.	Per cent NaCl by weight	Pounds NaCl per gallon solution	Freezing point, ° F.
1.00000	0	0	0	0	+32.0
1.00725	1.04	3.8	1	0.084	30.5
1.01450	2.07	7.6	2	0.169	29.3
1.02174	3.08	11.4	3	0.256	27.8
1.02899	4.08	15.2	4	0.344	26.6
1.03624	5.07	18.9	5	0.433	25.2
1.04366	6.07	22.7	6	0.523	23.9
1.05108	7.06	26.5	7	0.617	22.5
1.05851	8.01	30.3	8	0.708	21.2
1.06593	8.97	33.9	9	0.802	19.9
1.07335	9.90	37.5	10	0.897	18.7
1.08097	10.86	41.3	11	0.994	17.4
1.08859	11.80	45.2	12	1.092	16.0
1.09622	12.73	49.2	13	1.190	14.7
1.10384	13.64	53.0	14	1.289	13.4
1.11146	14.54	56.8	15	1.389	12.2
1.11938	15.46	60.6	16	1.495	11.0
1.12730	16.37	64.4	17	1.602	9.8
1.13523	17.27	68.2	18	1.719	8.5
1.14315	18.16	71.9	19	1.819	7.3
1.15107	19.03	75.5	20	1.928	6.1
1.15931	19.92	79.1	21	2.037	5.0
1.16755	20.80	83.0	22	2.147	3.9
1.17580	21.68	86.9	23	2.266	2.8
1.18404	22.54	90.9	24	2.376	1.7
1.19228	23.39	94.7	25	2.488	+ 0.5
1.20098	24.27	98.5	26	2.610	− 1.1
1.20433	24.60	100	26.395	2.661	1.6

Temperature correction 1° salometer for every 7½° F. added to reading for temperatures above 60° F., subtracted for those below.

There is also a salometer scale in use with 1° equal to ¼ per cent NaCl.

0 = 1.0000 specific gravity 100 = 1.19228 specific gravity, or 25 per cent NaCl.

CURRENT PETROLEUM LITERATURE

BY

DAVID T. DAY

The classic work of S. F. Peckham, in his review of the petroleum industry for the tenth census, the unequaled diligence of Sir Boverton Redwood, and lately the work of Miss Elizabeth H. Burroughs, of the Bureau of Mines, have contributed a wealth of bibliographic data concerning the petroleum industry. It is better to refer the reader to these authorities than to attempt to furnish any additional petroleum bibliography within the limits of a single chapter of this handbook. The reader, however, may value the following lists of present-day sources of most reliable information as to the ever-changing phases of petroleum development.

In few lines of industrial specialization is the public so thoroughly and continuously provided with reliable information as in the petroleum industry. The importance of the subject has been recognized by special appropriations to scientific branches of the Government, which have enabled the public to rely upon well-known Government offices for authentic information on each special phase of the industry.

The primary Government agency to afford systematic information on petroleum was the Mineral Resources Division of the U. S. Geological Survey. This Division has now achieved the publication of a report on petroleum production every month. It has given nearly forty years of continuous service in furnishing statistics, with steadily increasing accuracy, showing the amount and value of petroleum produced in the United States. It has supplemented this information by authoritative reports on the conditions of occurrence of oil and on the chemical characteristics of the products of each field. The Geological Survey is also responsible by law for the publication of official information as to the geological conditions governing the oil pools in the United States, for exploration for oil on the public lands, and for topographic and geologic maps of American oil-fields, with such investigations as are from time to time authorized regarding oil-fields in foreign lands. Much information has also been given as to the utilization of various oils, a line of investigation which has now become a function of the Federal Bureau of Mines. This organization has become an authoritative source of information as to refinery statistics (published monthly) and other features of the utilization of petroleum. It carries on general systematic studies of improvements in the methods of drilling, producing, transporting and refining crude oil, as well as the natural-gas gasoline industry, and cooperates with other organizations in the study of oil-testing methods. The Bureau of Mines has taken the lead in petroleum specifications for the various Government Departments.

The Bureau of Standards is authorized to establish standard tests for petroleum products and to standardize instruments for this kind of work. This has resulted in many publications which should become part of the plant of every oil engineer.

The Government offices cited above have absorbed most of the special lines of investigation concerning petroleum which developed during the period of the war, but the Federal Trade Commission and the Bureau of Internal Revenue publish occasional pamphlets resulting from special investigations pertinent to their bureaus. The Interstate Commerce Commission is responsible for regulations governing the interstate transportation of oil products.

The publications of the Government offices can be obtained by application to the Directors of the different Government Bureaus until the free edition is exhausted, and then may be obtained at small prices by application to the Superintendent of Documents, Government Printing Office, Washington, D. C. It is usually possible to receive lists of oil publications through this agency. The Bureaus themselves publish, at frequent intervals, circulars describing their recent publications.

The consideration of serials which appear regularly begins with the bulletin sent weekly to its members by the office of the American Mining Congress, in Washington, and a similar bulletin which the American Petroleum Institute, of New York, sends to its members once a week, or more frequently when occasion requires. The American Mining Congress assumes the responsibility to its members especially for news of coming national legislation concerning petroleum; while the American Petroleum Institute covers the whole petroleum field very broadly. It issues regularly an estimate of the previous week's production of petroleum, chiefly valuable as to the rate of increase or decrease, also a weekly statement of the imports of mineral oil, and, monthly, an analysis of the production and consumption of petroleum, based on official government figures, issued by the Geological Survey and the Bureau of Mines. Reports of various Institute departments and committee activities, and the complete proceedings of the Institute annual meetings, including addresses delivered and technical papers presented, are also included in the bulletin.

Credit must be given to the *Oil City Derrick* as the first regular reliable source of information as to the amount of oil run through the pipe-lines of the country every week, and as to the general news concerning oil-field development. The enormous value of this publication in aiding the development of the petroleum industry cannot easily be stated.

The chief journals which have followed the *Derrick*, and which have established and sustained a reputation for enterprise and accuracy, include the *Oil, Paint and Drug Reporter* (the petroleum section of which is now published and known as the *International Petroleum Reporter*), *Oildom*, the *Oil and Gas Journal*, etc.

CURRENT SOURCES OF PETROLEUM INFORMATION

Authorities	Publications	Chief Contributions on
U. S. Geological Survey	Bulletins, professional papers, monographs, "Mineral Resources" report, and maps	Conditions of occurrence, mineral characteristics and statistics of production, monthly and annually
Bureau of Mines	Bulletins, technologic papers, special reports of investigations	Petroleum technology, refinery statistics, petroleum specifications
Bureau of Standards	Bulletins, technologic papers and reports of special investigations	Testing methods, and standardization of apparatus
Federal Trade Commission	Special reports.	Investigation of special trade problems
Interstate Commerce Commission	Bulletins	Petroleum traffic regulation
Bureau of Internal Revenue	Annual reports, etc.	Depletion of oil properties and depreciation of equipment

CURRENT SOURCES OF PETROLEUM INFORMATION—*Continued*

Authorities	Publications	Chief Contributions on
Department of Commerce	Weekly commerce reports	Consular reports on foreign oil conditions and trade opportunities
American Mining Congress	Weekly bulletin to members, and monthly journal	Mining legislation
American Petroleum Institute (in future, publications of Research Bureau)	Weekly bulletin, annual report, etc. Co-operative work with other institutions	Estimates of production, imports, etc.; results of investigation by the Institute into petroleum technology and allied arts and sciences
American Society for Testing Materials	Circulars and proceedings	Authoritative testing methods
American Institute of Mining and Metallurgical Engineers	Bulletins and transactions	Occasional papers on all phases of the petroleum industry, with discussions
Oil, Paint and Drug Reporter (petroleum section now published separately and called the International Petroleum Reporter)	Weekly	General news
Oildom	Monthly	Corporation statistics
The Oil and Gas Journal	Weekly	General oil information
Bulletin of the American Association of Petroleum Geologists	Semi-monthly	Oil geology
Bureau of Mines (Canadian)	Reports of special investigations	Petroleum occurrence and technology
Canadian Mining Journal	Monthly	Oil in Canada
Engineering and Mining Journal	Weekly	Notes on new oil discoveries, occasional technical articles
Institution of Petroleum Technologists (London)	Monthly	Lectures and discussions
Mining and Oil Bulletin	Monthly	Conditions on the West Coast
National Petroleum News	Monthly	General news
Natural Gas and Gasoline Journal	Monthly	Natural gas and gasoline from gas
Natural Gas Association of America, proceedings	Monthly	Natural gas and gasoline from gas
Oil Age	Monthly	General oil news
Oil Weekly	Weekly	General
Oil and Gas News	Semi-monthly	General
Oil Engineering and Finance (London)	Weekly	Production, utilization and investments
Petroleum Age	Monthly	General oil news
Petroleum Times (London)	Weekly	Review of oil shipping and oil corporations, occasional technical articles

CURRENT SOURCES OF PETROLEUM INFORMATION—*Continued*

Authorities	Publications	Chief Contributions on
Moniteur du Pétrole Roumain (Bucharest)	Monthly	Corporation statistics
Petroleum World		General oil news
Standard Oil Bulletin	Monthly	Statistics and prices
Texaco Star	Monthly Monthly	Information as to oil in Gulf States
State geological surveys and mining bureas	Occasional reports	Occurrence
California State Mining Bureau	Bulletins at frequent intervals	Statistics; occurrence, and control of water

SOME GENERAL BOOKS ON PETROLEUM

Abraham, Herbert, Asphalts and Allied Substances, New York, D. Van Nostrand Co., Second Edition, Revised, 612 pp., 1920.

Ambrose, A. W., Underground Conditions in Oil Fields, U. S. Bureau of Mines Bull. 195, 238 pp., 1921.

Andros, S. O., The Petroleum Handbook, Chicago, The Shaw Publishing Co., 206 pp., 1919.

Bacon, R. F., and Hamor, W. A., The American Petroleum Industry, New York, McGraw-Hill Book Co., Inc., 2 volumes, 1916.

Beal, C. H., The Decline and Ultimate Production of Oil Wells, with Notes on the Valuation of Oil Properties, U. S. Bureau of Mines Bull. 177, 215 pp., 1919.

Beal, C. H., and Lewis, J. O., Some Principles Governing the Production of Oil Wells, U. S. Bureau of Mines Bull. 194, 58 pp., 1921.

Cox, G. H., Dake, C. L., and Muilenburg, G. A., Field Methods in Petroleum Geology, New York, McGraw-Hill Book Co., Inc., 305 pp., 1921.

Craig, E. H. C., Oil-finding, London, Edward Arnold, Second Edition, 324 pp., 1920.

Danby, Arthur, Natural Rock Asphalts and Bitumens, London, Constable & Co., Ltd., 244 pp., 1913.

Day, David T., Handbook of the Petroleum Industry, New York, John Wiley & Sons, Inc., 1922.

Ellis, Carleton, and Meigs, Joseph V., Gasoline and Other Motor Fuels, New York, D. Van Nostrand Co., 709 pp., 1921.

Emmons, W. H., Geology of Petroleum, New York, McGraw-Hill Book Co., Inc., 610 pp., 1921.

Engler, C., and Höfer, H. v., Das Erdöl, 5 volumes, Leipzig, 1913–19.

Hager, Dorsey, Practical Oil Geology, New York, McGraw-Hill Book Co., Inc., 253 pp., 1919.

Hager, Dorsey, Oil-field Practice, New York, McGraw-Hill Book Co., Inc., 310 pp., 1921.

Hamor, W. A., and Padgett, F. W., The Technical Examinations of Crude Petroleum, Petroleum Products and Natural Gas, New York, McGraw-Hill Book Co., Inc., 591 pp., 1920.

Hayes, C. W., Handbook for Field Geologists, Third Edition, Revised and Rearranged by Sidney Paige, New York, John Wiley & Sons, Inc., 166 pp., 1921.

H. M. Petroleum Department and H. B. Cronshaw, Petroleum, London, Imperial Institute Monograph, 110 pp., 1921.

Johnson, R. H., and Huntley, L. G., Principles of Oil and Gas Production, New York, John Wiley & Sons, Inc., 371 pp., 1916.

Johnson, R. H., Huntley, L. G., and Somers, R. E., The Business of Oil Production, New York, John Wiley & Sons, Inc., 1922.

McLaughlin, R. P., Oil Land Development and Valuation, New York, McGraw-Hill Book Co., Inc., 196 pp., 1913.

Paine, P. M., and Stroud, B. K., Oil Production Methods, San Francisco, Western Engineering Publishing Co., 239 pp., 1913.

Panyity, L. S., Prospecting for Oil and Gas, New York, John Wiley & Sons, Inc., 249 pp., 1920.

Pogue, J. E., The Economics of Petroleum, New York, John Wiley & Sons, Inc., 375 pp., 1921.

Redwood, Sir Boverton, Petroleum, London, Charles Griffin & Co., 3 volumes, 1913.

Thompson, A. Beeby, Oil-field Development and Petroleum, Mining, London, Crosby Lockwood & Sons, 648 pp., 1916.

U. S. Geological Survey, World Atlas of Commercial Geology, Part I, Distribution of Mineral Production, Washington, 1921. A section (pp. 17–23, plates 9–16) on petroleum, oil shale, and natural gas.

U. S. Internal Revenue, Treasury Dept., Manual for the Oil and Gas Industry under the Revenue Act of 1918, Revised Edition, 245 pp., 1921.

Warner, C. A., Field Mapping for the Oil Geologist, New York, John Wiley & Sons, Inc., 145 pp., 1921.

Ziegler, Victor, Popular Oil Geology, New York, John Wiley & Sons, Inc., 171 pp., Second Edition, 1920.

GLOSSARY

The following pages present a collection of the terms in common use in the petroleum industry, especially those to which that industry has given a meaning different from the ordinary dictionary meaning. The effort has also been made to give an exact statement of many terms which are frequently used without careful definition. The material has been gathered primarily from the definitions given by the authors themselves and found in the several chapters of this handbook. The glossary of mining terms by A. H. Fay, published by the Bureau of Mines, and that in Bacon and Hamor's "American Petroleum Industry," have been freely drawn upon, as have also the "Coal Miners' Pocket Book," and other authorities. Exact definitions from authoritative dictionaries have been inserted where it has seemed advisable, and credit for the source of the definitions is given, where practicable, for each item.

Abney level.—An instrument having a vertical graduated arc and a movable vernier. It can be used also as a clinometer.

Absolute atmosphere.—An absolute unit of pressure, equal to one million times the pressure produced on a square centimeter by the force of one dyne.

Absolute pressure.—That measure of pressure which includes atmospheric pressure. Pressure expressed in absolute measure, commonly in absolute atmospheres (Century). Pressure reckoned from a vacuum.

Absolute temperature.—The temperature measured from the absolute zero of temperature on the absolute or thermodynamic scale of temperature. This scale differs slightly from that of an air thermometer, and by the absolute temperature is often meant the temperature on the latter scale above the absolute zero (Century).

Absolute zero.—That point of temperature at which a body would be wholly deprived of heat, and at which a perfect gas would exert no pressure; supposed to be $-273°$ C., or $-461°$ F., or $-219°$ Réaumur; used on the only thermodynamic scale (Standard).

Absorb; Absorption.—To take up by cohesive, chemical or any molecular action, as when charcoal absorbs gases (Webster).

Absorption oil.—An oil containing little or no gasoline, used in the absorption process for extracting gas from natural gas. Mineral seal oil (q.v.) is preferred because of its low viscosity, good absorbent power and low cost.

Absorption process.—Gasoline.—The process of extracting gasoline from natural gas by passing the gas through a medium capable of absorbing the gasoline, such as oil or charcoal. The gasoline is subsequently distilled from the absorbing medium and collected.

Acetone.—An inflammable liquid (C_3H_6O) with a biting taste, obtained by the destructive distillation of acetates and various organic compounds. It is used in making chloroform and as a solvent for fats, camphor, and resins (Standard).

Acetylene.—The most brilliant illuminating gas (C_2H_2); it may be produced synthetically from its elements by incomplete combustion of coal gas, and commercially

from calcium acetylid (calcium carbide, CaC_2) by the action of water (Standard). Much used for underground lighting.

Acid.—Sharp or biting to the taste, having acid-forming constituents present in excess of the proportion required to form a neutral or normal compound (Webster).

In modern chemistry an acid may be regarded as a salt of hydrogen, or as a compound containing one or more atoms of hydrogen, which may be displaced by a metal, or by a radical possessing, to a certain extent, metallic functions (Century).

Acid tar.—See Sludge.

Acid blow case.—A small iron tank of heavy construction, from which the sulphuric acid used in the process of " treating " is blown by compressed air to the agitator. When the tank is of cast iron, it is usually termed an " egg " (A. D. Smith).

Acid coke.—A by-product obtained in treating dry-run tar, at an elevated temperature, with sulphuric acid; it is a soft, solid coke containing free carbon, complex heavy hydrocarbons, free sulphur, and sulphuric acid (A. D. Smith).

Acid heat test.—The increase in temperature produced by adding commercial sulphuric acid to a petroleum distillate under standard test conditions (Delbridge).

Acid number.—The number of milligrams of potassium hydroxide necessary to neutralize one gram of oil.

Acid restoring plant.—An auxiliary department of certain refineries, in which sludge acid is separated into acid oil, tar, and weak sulphuric acid, with provision for reconcentrating the latter to 66° Bé. or 93.5 per cent acidity H_2SO_4 (commercial concentrated sulphuric acid) (A. D. Smith).

Acid sludge.—See Sludge.

Acid treatment.—The process of agitating petroleum products, particularly gasoline, kerosene, and lubricating stock, with sulphuric acid, to remove compounds causing undesirable color or odor.

Aclinic.—(Geology).—Without inclination or dip.

Adamantine drill; shot drill.—A core drill with chilled-steel shot employed in rotary drilling in very hard ground.

Adhesion.—A molecular force by which bodies of matter are caused to stick together (Rickard).

Adiabatic line.—The line indicating the relation between the pressure and volume of a gas, due to expansion or compression, when no transmission of heat takes place (Goldingham).

Adsorb.—To condense and hold a substance, usually a gas, on the surface of another substance, usually a solid; also to hold a mineral particle within a liquid interface.

Adsorption.—The adhesion of molecules of gases or dissolved substances to the surface of other bodies, usually solids, resulting in a relatively high concentration of the gas or solution at the point of contact.

Aeolian.—An adjective applied to rocks formed of wind-borne sands. Some such aeolian sands yield large quantities of oil; practically all the great Baku spouters have been obtained from sands of this class (Mitzakis). Also spelled Eolian.

Aerify.—To change into a gaseous form (Standard). To infuse or force air into; to combine with air (Webster).

Agitator.—An implement or apparatus for shaking and mixing (Webster). A mechanical apparatus employed in refining petroleum to keep the oil in constant motion when it is treated with sulphuric acid. Agitation on a large scale is now performed by means of compressed air or by mechanical stirring.

Air.—The mixture of gases that surrounds the earth and forms its atmosphere; composed by volume of 21 parts of oxygen and 78 parts of nitrogen; by weight of about 23 parts of oxygen and 77 of nitrogen. It contains also about 0.03 per cent of carbon dioxide, some aqueous vapor, and about 1 per cent argon.

Air condenser.—A surface condenser cooled by contact with air instead of water (Webster).

Air drive or air flooding.—Increasing the flow of oil in surrounding wells by forcing compressed air into centrally located wells.

Air gas.—A combustible gas made by saturating air with the vapor of some volatile hydrocarbon mixture, as gasoline, and used for lighting and heating (Webster).

Air lift.—An arrangement for raising water or other liquid from a well or sump, air under pressure being introduced near the foot of an open-ended pipe having a certain submergence. The column of solid and liquid in the pipe, because of the introduction of the air, is made lighter than the submergence column outside, and an upward flow within the pipe results (Fay).

Air pumping.—Pumping oil wells by means of the air-lift principle.

Alidade.—An instrument used in topographical surveying and particularly in oil geology. It consists, in its simplest form, of a pair of sights affixed to a straight-edge, so that the line of sight is parallel to the edge of the straight-edge. As generally used, the sights are replaced by a telescope containing cross-hairs and stadia-hairs.

Alkali.—In chemistry, any substance having marked basic properties. In its restricted and common sense, the term is applied only to hydroxides of potassium, sodium, lithium, and ammonium. They are soluble in water, have the power of neutralizing acids and forming salts with them, and of turning red litmus blue. In a more general sense, the term is also applied to the hydroxides of the so-called alkaline-earth metals—barium, strontium, and calcium.

Alkali liquor.—The spent liquor left after washing petroleum products, such as kerosene, with alkali. It usually contains phenols and sulphonates.

Alkali wash.—A process by which kerosene is treated with a solution of caustic soda, making it purer and more suitable for illuminating.

Alkyl-sulphur compounds.—Sulphur combinations occurring in petroleum in which the hydrogen content of the simple compound H_2S (hydrogen sulphide) has been wholly or in part replaced by organic radicals; such as (C_2H_5) HS, $(C_3H_7)_2$ S (A. D. Smith).

Allegheny formation.—The second, in order of age, of the formations comprised in the Pennsylvania series of strata in the bituminous coal districts of the Northern Appalachian field. It overlies the Pottsville formation (Fay).

Allotrophy; allotropism.—The capacity of existing in two or more conditions, that are distinguished by differences in properties. Thus, carbon occurs crystalline, as in the diamond, and amorphous, as in charcoal (Webster).

Aloes rope.—A special kind of rope, sometimes used in oil-well drilling, the breaking strain of which is 300 kg. per circular centimeter. It is manufactured from the aloe, a plant indigenous to Cape Colony (Mitzakis).

Alteration.—Strictly, any physical or chemical change in a rock or mineral, subsequent to its formation. As ordinarily used, however, the term excludes cementation

or induration of sediments to form hard rocks, and implies change to such an extent that new minerals or new rock textures have developed (La Forge).

Altitude.—Vertical distance or elevation above any given point or base-level, as the sea; height; hence, also, such distance numerically expressed (Standard).

Ambar.—The Russian name given to excavations dug around a derrick and forming small reservoirs, where the sand raised from the bore-hole is deposited. Also used as a temporary reservoir for oil (Mitzakis).

American paraffin oil.—An English term for kerosene of American origin (Bacon).

American pump.—A special kind of bailer, used in oil-fields for cleaning out wells (Mitzakis). See also Bailer and Sand pump.

American system of drilling.—See Cable system.

Ammonia.—A colorless gaseous compound of hydrogen and nitrogen (NH_3) with extremely pungent smell and taste. Specific gravity as compared with air, 0.589 (Webster).

Amorphous.—Without form; applied to rocks and minerals having no definite crystalline structure (Roy. Com.).

Amortization.—The repayment of a debt, principal and interest, in equal annual installments. Frequently used in finance as the extinction of a debt, regardless of the means employed (E. B. Skinner, p. 114). Important in connection with mining finance.

Amortize.—To clear off, liquidate, or otherwise extinguish, as a debt. To extinguish by periodically charging off a portion, so as to bring the value to par at maturity (Webster).

Analysis.—Specifically, in chemistry and mineralogy, the determination, by chemical methods, of the nature and proportionate amounts, and sometimes also of the manner of combination, of the elementary constituents of a compound substance, as a mineral or a rock. Also, loosely, a tabular statement of the result of such an analysis (La Forge).

Analyzer.—That part of a polariscope that receives the light after polarization, and exhibits its properties (Webster).

Aneroid barometer.—An instrument, operated by atmospheric pressure, used to determine elevations above sea level.

Angle of polarization.—That angle whose tangent is the index of refraction of a reflecting substance (Dana).

Anhydrous.—Destitute of water, especially water of crystallization (Webster).

Anthracite; hard coal.—A hard, black, lustrous coal, containing 85 to 95 per cent carbon, as against 70 to 80 per cent in bituminous or "soft" coal. See also Coal (U. S. Geol. Survey). Characterized by its small percentage of volatile matter, high specific gravity, hardness, nearly metallic luster, rich black color, and semiconchoidal fracture.

Anticlinal.—Of, or pertaining to, an anticline (Webster).

Anticlinal bulges.—Expansions and elevations in the crests of definite anticlines or continuous folds (Clapp).

Anticlinal flexure; anticlinal fold.—See Anticlinal; Anticline.

Anticlinal line or axis.—(Geology.) The medial line of a folded structure, from which the strata dip on either side (Century).

Anticline.—A fold or arch of rock strata, dipping in opposite direction from an axis (Webster).

Anytoles.—Proprietary preparations in which substances like phenol, cresol, volatile oils, camphors, etc., are dissolved in water by means of anytin, a substance formed by the action of sulphuric acid on various mineral oils, resin oils, and hydrocarbons (Bacon).

Apex.—(Geology.) The top of an anticlinal fold in strata.

Appalachian.—Of, or pertaining to, a system of mountains in the eastern United States, also incorrectly called Allegheny from its western range (Webster).

Apron ring.—The bottom ring of plates used in construction of a tank (A. D. Smith).

Arch.—See Anticline.

Archimedean screw.—A spiral screw, fitting closely in a tube, for raising water or other liquids, often used as a screw conveyor for grain, sand, gravel, and fine ore (Fay). See Screw conveyor.

Arenaceous.—An adjective applied to rocks that have been derived from sand or that contain sand (Kemp). Not to be confounded with siliceous.

Areometer.—An instrument for measuring the specific gravity of liquids, a hydrometer (Standard).

Argon.—A colorless, odorless gas contained in the air, of which it constitutes almost 1 per cent by volume. Symbol, A; atomic weight, 39.88; specific gravity, 1.4 (Webster).

Aromatic compounds.—Those derived from the series of hydrocarbons beginning with benzol or benzene, C_6H_6 as the initial member.

Artesian well.—A well bored down to a point, usually at considerable depth, where the water pressure, owing to the conformation of the strata, is so great as to force the water to the surface. Often applied to any deep bored well, even where pumping is necessary, as in an ordinary driven well.

Asphalt.—A black or brownish-black product having cementitious, waterproof, and usually resilient properties. Its technical definition is: Solid or semi-solid native bitumens, solid or semi-solid bitumens obtained by refining petroleum, or solid or semi-solid bitumens which are combinations of the bitumens mentioned, with petroleums or derivations thereof, which melt upon the application of heat, and which consist of a mixture of hydrocarbons and their derivatives of a complete structure, largely cyclic and bridge compounds (A. S. T. M. Standard, Serial Designation D8–18).

Asphalt.—A group of complex compounds of various hydrocarbons, part of which are oxidized or contain sulphur. Related in origin to petroleum. Varies from viscous liquid to a brittle solid. Also called mineral pitch. The same as asphaltum. See Elaterite, Gilsonite, Grahamite.

The name bitumen is often used as synonymous with asphalt, but is more properly the general name for all soluble bituminous materials obtained from the earth, including petroleum. Asphalt may be native or may result from the distillation of mineral oil; in the latter case it is known as petroleum asphalt, or petroleum pitch.

Asphalt-base petroleum.—Petroleum that yields asphalt and no paraffin when distilled. See Base.

Asphalt block pavement.—A pavement having a wearing course of previously prepared blocks of asphaltic concrete (Bacon).

Asphalt cement.—A fluxed or unfluxed asphaltic material, especially prepared as to quality and consistency, suitable for direct use in the manufacture of asphaltic pavements (Bacon).

Asphalt content.—The percentage by weight of 100-penetration asphalt contained in the substance tested (Delbridge).

Asphalt-earth pavement.—A pavement containing a mechanical mixture of asphalt with finely divided earthy material, such as clay (R. G. Smith).

Asphalt flux.—As steam-refined stock is produced from a paraffin-base crude, asphalt flux is obtained from an asphalt-base crude. There is naturally no fixed line of demarcation; fluxes low in asphalt are marketed as steam-refined stocks in periods of acute demand, and conversely, cheap stocks become flux products and road-oil bases in a slack lubricating market. Asphalt flux is often sold directly as road oil, and it forms the base for further reduced malthas, pitches, and oxidized asphalts (A. D. Smith).

Asphalt furnace.—A portable furnace in which asphalt is heated for use in roofing, paving, etc. (Century).

Asphalt macadam.—A broken stone pavement laid in a manner similar to ordinary macadam, except that the broken stone of the wearing course is coated and filled with asphalt applied by the pouring method after the stone has been placed on the road. Such applications may be made with hand pouring pots, or with mechanical pressure distributors (R. G. Smith).

Asphalt mastic pavements.—Asphalt mastic is a mechanically mixed asphalt mixture which is heated and mixed over a comparatively long period of time, forming a mass which may be poured into place and put into form by troweling, and which, when allowed to cool, sets in the required condition. This distinguishes it from sheet asphalt or asphaltic concrete mixtures, which are usually compressed into place, and which usually do not contain as much asphalt as the mastic pavement (R. G. Smith).

Asphalt rock.—Asphalt stone. Limestone impregnated with asphalt (Webster). This term is also applied to asphaltic sandstone.

Asphalted.—Literally, coated with asphalt. Usually some of the special compositions, such as California oil (which has an asphaltic base), coal tar, mineral wax, gilsonite or elaterite, are added to give the right consistency to suit the average temperature which prevails when the coating is used (National Tube Co.).

Asphaltene.—That portion of the asphalt which is soluble in carbon disulphide but not dissolved by 88° Bé. naphtha is called "asphaltene" (R. G. Smith).

Asphaltic.—Similar to, or essentially composed of, asphalt (Bacon).

Asphaltic concrete pavement.—A pavement composed of a mixture of asphalt with broken stone, broken slag, or gravel, together with sand and mineral filler. The term "concrete" presupposes a mechanical mixture prepared before laying (R. G. Smith).

Asphaltic limestones.—Limestones that have become impregnated with asphalt in varying proportions (R. G. Smith).

Asphaltic pyrobitumens. (Elaterite, wurtzilite, albertite and impsonite).—Natural asphaltic substances, generally containing less than 10 per cent of mineral matter, and characterized by their hardness and infusibility and the bitumen yielded on destructive distillation. Black in color, these four classes of substances merge or grade into one another, so that they may be roughly distinguished from one another by their bright to dull surfaces, and their conchoidal to hackly fractures (R. G. Smith).

Asphaltic sands.—Natural mixtures of asphalts with varying proportions of loose sand grains. The quantity of bituminous cementing material extracted from the

sand may run as high as 12 per cent, and this bitumen is composed of a soft asphalt which rarely has a penetration as low as 60° (R. G. Smith).

Asphaltum.—See Asphalt.

Assessment work.—The annual work upon an unpatented mining claim on the public domain necessary under the United States law for the maintenance of possessory title thereto. Same as Annual labor (Min. Stat. pp. 233–253).

Astatki; ostatki.—A Russian name for a petroleum residue now used as fuel. Until 1870 it was considered a useless article and was disposed of by burning in open pits near the refineries (Mitzakis).

Atmosphere.—The whole mass of air surrounding the earth. The pressure of air at the sea level, used as a unit. See also Atmospheric pressure (Webster).

Atmospheric pressure.—The pressure of air at the sea level, exerted equally in all directions. The standard pressure is that under which the mercury barometer stands at 760 millimeters. It is equivalent to about 14.7 pounds to the square inch (Webster).

Atom.—According to the atomic theory, the smallest particle of an element that can exist either alone or in combination with similar particles of the same or of a different element; the smallest particle of an element that enters into the composition of a molecule (Webster).

Atomic weight.—The weight of an atom of a chemical element as compared with that of an atom of hydrogen (Standard).

Atomization.—The method by which a jet of steam, or compressed air, is made to divide a fluid finely, as in an oil-burning furnace (Fay).

Atomizer.—An apparatus for converting liquid into spray. See also Atomization.

Atreol.—A petroleum product resulting from the action of sulphuric acid on certain petroleum distillates. Properly refined and combined with ammonia, it produces the active principle of atreol, the ammonium atreolate. It is soluble in water and alcohol, and is miscible with petroleum and lanolin. See Ichthyol.

Auger stem.—The heavy iron bar attached just above the bit in a string of tools (Sands).

Autun shale oil.—A name applied to a certain kind of illuminating oil, so called through being extracted from the bituminous shale found at Autun in France (Mitzakis).

Avoirdupois.—The system of weights used in England and the United States for the ordinary purposes of trade, of which the fundamental unit is the pound of 16 ounces or 7000 grains (Standard). The avoirdupois pound is equivalent to 14.583 troy ounces, 453.6 grains.

Axis.—A straight line, real or imaginary, passing through a body, on which the body revolves or may be supposed to revolve; a line passing through a body or system, around which the parts are symmetrically arranged (Fay).

See Anticlinal axis and Synclinal axis. Often used synonymously with anticline; thus, the "Brady's bend axis" for the "Brady's bend anticline" (Chance).

(Geology.) The central or dominating region of a mountian chain, the line of which follows the crest of a range, thus indicates the position of the most conspicuous part of the uplift (Fay).

Azoic.—Formerly, that part of geologic time represented by the pre-Cambrian stratified rocks; also the rocks formed during that time. Later restricted to the period and system now generally called Archean. Now practically obsolete (La Forge).

Back pressure valve.—A valve similar to a low-pressure safety valve, but capable of being opened independently of the pressure, thereby giving free exhaust (National Tube Co.).

Bailer.—The apparatus used to remove mud, sand, and water from a well. It is essentially a long pipe fitted with a dart valve at the bottom. See also Sand pump. Occasionally used, instead of a pump, to recover the oil.

Bailing.—One of the most common ways by which the water and drillings that collect at the bottom of a well during drilling are brought to the surface. In Russia, the petroleum itself is also removed by a bailer.

Barograph.—A self-recording aneroid barometer (Lahee).

Barometer.—An instrument for determining the weight or pressure of the atmosphere, and hence for judging of probable changes of weather, or for ascertaining the height of any ascent, etc. (Webster).

Base.—(1) A compound capable of reacting with acids to form salts.

(2) The artificial foundation of a pavement.

(3) The residuum from the distillation of petroleums. When paraffin is obtained from the petroleum, the original oil is said to have a paraffin base; when the residue is entirely asphaltic, the original petroleum is said to have an asphaltic base. Some petroleums have both an asphaltic and a paraffin base and are therefore called paraffin-asphalt petroleums.

Base map.—A map, usually drawn with considerable accuracy, which serves as a base for geologic work.

Basic.—(Chemistry.) Performing the office of a base in a salt; having the base in excess. Having more than one equivalent of the base for each equivalent of acid (Century). Compare acidic (Kemp).

Batch still.—A still without connections for continuous feed or outflow; a discontinuous still (A. D. Smith).

Battery.—A series of stills or boilers set in continuous masonry.

Baumé gravity.—Specific gravity expressed on the Baumé scale for liquids lighter than water (Delbridge).

Baumé scale.—An arbitrary scale of the relative density of liquids.

Bed.—The smallest division of a stratified series, marked by a more or less well-defined divisional plane from its neighbors above and below (Kemp).

Bedding.—See Stratification.

Bell socket.—A fishing tool.

Bench.—(Geology.) An outcropping bed which forms a conspicuous, relatively horizontal ledge.

Bench level.—A level used in setting up a machine to bring its bed into an exactly horizontal position (Century).

Bench mark.—A mark or monument, the elevation of which is known or assumed, used as a reference point by a surveyor.

Bend.—(1) A curved length of pipe struck to a larger radius than the elbow.

(2) Pipe bent to 45, 90 or 180° is often specified as $\frac{1}{8}$, $\frac{1}{4}$ or $\frac{1}{2}$ bends.

(3) A slight bend is often called a spring (Poor usage) (National Tube Co.).

Benzene; benzol.—A hydrocarbon of the composition C_6H_6. The initial member of the aromatic or benzene (C_nH_{2n-6}) series. The properties of the series are consistently expressed by the 6 atoms in a ring with double linkage between each alternate pair. While benzene occurs to a slight extent in most natural petro-

leums, it is chiefly found in East Indian and Californian petroleums. It is usually obtained from the light oils from coal tar.

Benzine.—A colorless, inflammable and volatile liquid obtained from petroleum by fractional distillation and consisting of various hydrocarbons. Called also petroleum spirit (Standard). It is totally distinct from the aromatic hydrocarbon benzene.

Benzine; naphtha tops.—Usually the first products obtained in distillation, ranging from water-white to standard white in color, 400° to 500° F. end-point, and from 66° to 48° Bé. gravity, depending on the nature of the crude cuts employed (A. D. Smith).

Benzol.—The commercial name applied to benzene not necessarily pure. See also Benzine.

Berea sandstone.—Berea grit. A rock formation consisting of fine-grained sandstone and grit, generally considered as the base of the Carboniferous system in Ohio. It is one of the principal oil-bearing formations of the State (La Forge).

Bermudez asphalt.—A relatively pure black bitumen. It is soft, breaks with a conchoidal fracture, and melts at a low temperature. It takes its name from the state of Bermudez, in Venezuela, where two large deposits have been found. Its chief use is in the paving industry (R. G. Smith).

Bevel.—(Geology.) The angle which one surface makes with another when they are not at right angles (Webster).

Binder.—The course frequently used in a sheet-asphalt pavement between the concrete foundation and the sheet-asphalt mixture of graded sand and asphalt cement (Bacon).

Bit gage.—An iron ring of known diameter used to test the bit during dressing to determine when it has reached correct size (Sands).

Bit hook.—A tool for straightening a lost bit in the hole (Sands).

Bitulithic.—A kind of paving consisting of broken stone cemented with bitumen or asphalt (Webster).

Bitumen.—See Asphalt. (1) A general name for various solid and semi-solid hydrocarbons. In 1912, the term was used by the American Society for Testing Materials to include all those hydrocarbons which are soluble in carbon bisulphide, whether gases, easily mobile liquids, viscous liquids, or solids (U. S. Geo. Survey).

(2) Bitumen, in the asphalt trade, is defined as a mixture of native or pyrogenous hydrocarbons and their non-metallic derivatives which are soluble in carbon disulphide (R. G. Smith).

Bituminous.—Containing much organic, or at least carbonaceous matter, mostly in the form of the tarry hydrocarbons which are usually described as bitumen (Kemp). Having the odor of bitumen. Often applied to minerals (Dana).

Bituminous cement.—A bituminous material suitable for use as a binder, having cementing qualities which are dependent mainly on its bituminous character (Bacon).

Bituminous concrete pavement.—A pavement, composed of stone, gravel, sand, shell or slag, or combinations thereof, and bituminous materials, incorporated by mixing methods (Bacon).

Bituminous limestone.—A limestone impregnated with bituminous material and emitting a fetid odor when rubbed. Called also stink stone and swinestone (Standard).

Bituminous macadam pavement.—A pavement having a wearing course of macadam, with the interstices filled by penetration methods with a bituminous binder (Bacon).

Bituminous sandstone.—See Sandstone.

Bituminous shale.—A shale containing hydrocarbons or bituminous material; when rich in such substances it yields oil or gas on distillation. Also called pyroschist or oil-shale (Standard).

Bituminous surface.—(Paving.) A superficial coat of bituminous material, with or without the addition of stone or slag chips, gravel, sand, or material of similar character (Bacon).

Bitusol.—Dispersed solid colloids in solution in bitumen.

Blackjack.—Crude black oil used to lubricate mine-car wheels.

Black oil.—The residuum from a wax "cracking" still is sold as black oil when obtained from an asphalt-free wax distillate The term is rather generally applied to any dark-colored lubricating oil of moderate flash and viscosity, suitable for heavy lubrication, such as that of railroad car journals, gears, cables, etc. (A. D. Smith).

Blaes.—In Scotland, the brownish oil-shales are interstratified with non-bituminous or less bituminous beds, sometimes of a bluish-gray color. These are termed "blaes" by the shale miners (Bacon).

Blanket.—A bituminous surface of appreciable thickness, generally formed on top of a roadway by the application of one or more coats of bituminous material and sand. Also called Carpet (Bacon).

Blank flange.—A flange which is not drilled but which is otherwise complete (National Tube Co.).

Blasting.—A method of loosening or shattering masses of solid matter, by means of explosive compounds. Where petroleum occurs in a dense hard ock, recourse must sometimes be had to the use of explosives, the effect of these being to set up a subterranean disturbance, which may thus be the means of giving freer movement to the oil (Mitzakis). See Shooting.

Blasting oil.—Same as Nitroglycerin (Century).

Blau or blue gas.—A mixture of volatile hydrocarbons, such as propane, butane, the pentanes, etc., in solution under pressure. The pressure solution is put into steel cylinders, and is thus available for transport. Blau gas is used for illuminating, heating and power purposes (Bacon).

Bleacher.—A rectanulgar or cylindrical upright tank having a roof provided with hatches or glass panels to allow escape of vapor or admit sunlight; a tank in which burning or lubrication oil is "brightened" (A. D. Smith).

Bleeding.—Testing a tank of oil for water and sediment, by drawing off at the bottom.

Blending.—The addition of one oil to another so that the mixture or blend is homogeneous in all its parts

Blind flange.—The flange used to close the end of a pipe. It produces a blind end which is also called a dead end (National Tube Co.).

Blind splicing.—Joining the ends of a steel cable by removing the hemp core to accommodate the ends of the strands (Sands).

Bloom.—The fluorescence of petroleum and its products, especially lubricating oils.

Blow-out.—A sudden or violent escape of gas or air.

Blow-out prevention.—A heavy casing head control filled with special gates or disks which may be closed around the drill pipe or which completely close the top of the casing if the drill pipe is withdrawn (Sands).

Blown oils.—Semi-solid or solid products obtained primarily by the action of air upon originally fluid native bitumens, which are heated during the blowing process. Also called " condensed " oils.

Blue oil.—(1) A mixture of heavy oils and paraffin obtained in the distillation of ozokerite (Webster).

(2) In the Scottish shale-oil industry, the oil produced from heavy oil and paraffin by cooling and pressing for separation of hard paraffin scale. It is refined and fractioned into lubricating oils (Bacon).

Body.—The thickness of a lubricating oil or other fluid; also the measure of that thickness expressed in the number of seconds in which a given quantity of the oil at a given temperature flows through an aperture. See Viscosity (C. and M. M. P.).

Boghead coal.—A dark brown variety of cannel coal, valuable as a source of paraffin oils and gas (Webster).

Boiler flange.—See Saddle flange.

Boiling.—Heated to the point of bubbling; heaving with bubbles (Webster).

Boiling point.—The temperature at which a liquid begins to boil, or to be converted into vapor by bubbles forming within its mass. It varies with the pressure In water, under ordinary conditions, it is 212° F. or 100° C., but it becomes less with lessened atmospheric pressure, as in ascending a mountain, being lowered about 1° F. for every 550 feet of ascent (Standard).

Bone-black.—The black carbonaceous substance into which bones are converted by calcination in closed vessels; also called animal black, or charcoal (Webster).

Boot jack.—A fishing tool.

Bore.—(1) To make a hole or perforation with a boring instrument; to cut a circular hole by rotary motion of a tool, as to bore for water, oil, etc. (Fay). (2) A hole made by boring.

Borebit.—A rock-boring chisel (Standard).

Bore-hole.—A hole made with a drill, auger, or other tools, for exploring strata in search of minerals, for water supply, for blasting purposes, for proving the position of old workings, faults, and letting off accumulations of gas or of water (Cresley) See also Oil well.

Bore-hole pump.—A pump for use in a bored well (Standard).

Boring.—The act or process of making a hole with a boring tool; a hole so made; material removed by boring (Standard).

Boring bar.—A revolving or stationary bar carrying one or more cutters or drills for boring.

Boring contract.—See Lease.

Boring rod.—A rod made up of segments, carrying at its lower end a tool for earth-boring or rock-drilling (Webster).

Bottom hole packer.—A type of packer used at the bottom of the casing (Sands).

Bottoms (still bottoms).—The crude distillate left in the bottom of a still after distillation, or that part of the crude which does not vaporize and pass through the condenser.

Bottom settlings; " B. S."—A term quite generally applied to the emulsions of oil, water, and mud which settle out of crude in storage, and which would have no value as a petrolatum base. The " B. S." from Pennsylvania crude is, however,

an emulsion of water and amorphous wax, and when properly freed from foreign matter forms an excellent base for the light yellow and darker grades of petrolatum (A. D. Smith).

Bottom sheets.—The steel plates forming the bottom of an oil still (A. D. Smith).

Bottom water.—In oil wells, water that lies below the productive sand, and is separated from it. Compare Top water, Edge water (U. S. Geol. Survey).

Box.—See Joint.

Bradenhead.—In oil-well drilling, an iron or steel head screwed into the top of the casing. The inner pipe projects up through it and is packed with some pliable substance, preferably rubber. The bradenhead is used to confine gas between the tubing and casing or between two strings of casing, and has an outlet through which gas may be piped away. More commonly called stuffing-box casing-head (Fay).

Bradenhead gas.—In oil wells, natural gas inclosed or confined by a bradenhead. It applies to all the gas that lies above the oil and through which the drill must go to reach the lower and more profitable oil sands (Fay).

Brake, or actual horse-power.—The power developed by an engine, as measured at the crank shaft or flywheel by the Prony brake or other device (Goldingham).

Beaman stadia arc.—A logarithmic calculator for solving right triangles, fixed to the vertical arc of a transit.

Brea.—Sand or soil impregnated with petroleum from seepages, the volatile constituents having evaporated. A term in common usage in California, where the pressure of brea is considered one of the most reliable surface indications of petroleum.

Break.—A fault, rupture or fracture (Webster).

Break-out tongs.—A heavy pipe wrench used to connect and disconnect drill pipes (Sands).

Briggs standard.—A list of pipe sizes, thicknesses, threads, etc., compiled by Robert Briggs, about 1862, and subsequently adopted as a standard (National Tube Co.).

Brine.—Water strongly impregnated with salt (Webster).

Briqueting.—A process by which coal dust is bound with asphalt, in briquets, and thus made readily available for commercial use. Asphalt is the best known binder and is used at the rate of 4 to 6 per cent by weight of the coal dust. It is usually heated and intimately mixed mechanically, after which the dough is pressed into molds, compressed into briquets and cooled (R. G. Smith).

British thermal unit.—The $\frac{1}{180}$ part of the heat required to raise the temperature of 1 pound of water from 32° F. to 212° F.; substantially equal to that required to raise the temperature of 1 pound of water from 63° F. to 64° F. Abbreviated as B.t.u.

Brunton.—A combination compass, clinometer, and transit, of pocket size named for its inventor.

"B.S."—See Bottom settlings.

B.t.u.—Abbreviation for British thermal unit.

Bull plugs.—Plugs which are temporarily screwed into the end of an unfinished pipe-line to keep out dirt, small animals, etc. (Towl).

Bull pump.—A direct single-acting pump, the steam cylinder of which is placed over the top of a shaft or slope, and the piston rod attached to the pump rods. The steam lifts piston and pump rods, and the weight of these produces the down stroke (Raymond).

Bull rope.—In well boring, the rope from which the boring tools are suspended and by which they are worked (Webster).

Bull wheels.—Large pulleys, rope-driven from the main shaft of a rig, used to raise and lower the bit or fishing tools and sometimes the casing (Sands).

Bumper.—A device used to loosen the tools when drilling is carried on without jars (Sands).

Bumping.—A refinery colloquialism applied to the violent boiling of a water-containing petroleum product. It usually ceases before the water is entirely evaporated (A. D. Smith).

Burning-oil.—A common name for kerosene.

Burning point.—The temperature at which a volatile oil in an open vessel will ignite from a flame held close to its surface, and continue to burn. Used to determine the safety of kerosene and other illuminants. See Fire test.

Burrell gas detector.—A device to obtain a safe, rapid and accurate determination for low percentage of methane inside the mine. Complete combustion of the methane takes place within the apparatus, and the percentage is measured volumetrically (Fay).

Bushing.—A pipe-fitting for the purpose of connecting a pipe with a fitting of larger size, being a hollow plug with internal and external threads to suit the different diameters. See Flush bushing (National Tube Co.).

Butted and strapped joint.—A joint where the ends of two pieces of pipe are united by a sleeve and riveted thereto. The strap may be inside or outside and may be single or double riveted (National Tube Co.).

Buttweld.—Welded along a seam that is not scarfed or lapped (National Tube Co.).

By heads.—Term used when a well flows intermittently (Sands).

By-pass.—A small passage to permit equalizing the pressure on the two sides of a large valve so that it may be readily opened or closed (National Tube Co.).

By-pass valve.—A small pilot valve used in connection with a larger valve to equalize the pressure on both sides of the disk of the larger valve before the larger valve is opened (National Tube Co.)

By-product.—A secondary or additional product (Webster).

Cable.—Same as Cable-laid rope; a fiber cable consists of three hawsers laid up left-handed (C.M.P.). A steel rope for hoisting or for aerial trams.

Cable-laid rope.—Wire cables made of several ropes twisted together, each rope being composed of strands or direction of twist. A fiber cable-laid rope is composed of strands of hawser-laid rope, twisted right-handed (C.M.P.)

Cable system.—One of the well-known drilling systems, sometimes designated as the American rope system. The drilling is performed by a heavy string of tools suspended from a flexible manila or steel cable to which a reciprocating motion is imparted by its suspension from an oscillating "walking beam." One end of the walking beam is above the mouth of the well when horizontal, and the other end is directly above a crank attached to the band-wheel shaft (Mitzakis). Also called standard or percussion system.

Cable tools.—The apparatus used in drilling deep holes, such as artesian wells, with a rope, instead of rods, to connect the drill with the machine on the surface (Raymond).

Cage.—(1) A structure of elastic iron rods slipped into the bore-hole in rod-boring to prevent vibration of the rods.

(2) The container for the ball in a ball valve, such as found in the pump ordinarily used in oil production.

Calf wheel.—A drum usually operated by chain and sprockets from the main shaft of a rig, used in raising and lowering heavy strings of casing (Sands).

Calorie.—The amount of heat required to raise the temperature of 1 gram of water 1° Centigrade at or near the temperature of maximum density. Called small calorie (Webster).

Calorimeter.—Any apparatus for measuring the quantity of heat generated in a body or emitted by it, as by observing the quantity of a solid liquefied or of a liquid vaporized, or the amount of heat absorbed by a certain quantity of water, under given conditions (Fay).

Calorize.—To protect (iron or steel) from high temperature by coating the surface with a ferro-aluminum alloy (a trade expression).

Calyx.—A long cylindrical vessel of the same diameter as the core-barrel, which guides the bit, and receives the débris resulting from the action of the cutter. Its action is not unlike that of the diamond drill, and necessitates the use of a powerful water flush. The cutter, which takes the place of the diamond crown, has a number of long teeth which produce a chipping action when rotated by hollow flushing rods in the presence of a constant flow of water. Used in a system of oil-well drilling, originating in Australia. The great advantage of this system is that a core is extracted and preserved in a core-barrel and brought to the surface (Mitzakis).

Canadian pole system.—A system of oil-well drilling differing from the American cable system in that wooden rods screwed together are used instead of a rope. The Canadian pole is a useful all-round prospecting rig, and it is particularly suitable for regions where excessive caving makes it necessary to have some positive method of rotating the bit (Mitzakis).

Cannel coal.—A massive, non-coking, tough, clean, block coal, of fine, even, compact grain, dull luster and commonly conchoidal cross fracture, having a typical low fuel ratio, a high percentage of hydrogen, easy ignition, long yellow flame, black to brown greasy streak, and moderate ash. It is essentially a rock derived by solidification and partial distillation or oxidation of water-laid deposits consisting of, or containing, large quantities of plant spores and pollen grains and more or less comminuted remains of low orders of water plants and animals. There may be admixed greater or less quantities of mud, woody or peaty material (U. S. Geol. Survey). Has frequently been distilled for oil.

Cant.—A segment used in building the bull wheels of a rig (Sands).

Cap.—A fitting that goes over the end of a pipe, to close it, producing a dead end (National Tube Co.).

Capillarity.—The peculiar action by which the surface of a liquid, where it is in contact with a solid (as in a capillary tube) is elevated or depressed. Capillarity depends on the relative attraction of the molecules of the liquid for each other and for those of the solid. See also Surface tension (Webster).

Capping.—(1) The name given to a method by which the flow of a spouting oil well is stopped or restricted. When a very strong discharge of petroleum is expected, strong valves are attached to the casing, which permit the flow to be controlled, and in order to prevent these valves from being blown away, they are firmly anchored to the ground by means of long, heavy bolts (Mitzakis).

(2) The impervious beds overlying an oil sand. See Cap rock.

Cap rock.—A comparatively impervious stratum immediately overlying an oil-bearing rock.

Carbenes.—The difference between the amount of asphalt soluble in carbon disulphide and that dissolved by carbon tetrachloride is known as "carbenes" (R. G. Smith).

Carbide —(1) A binary compound of carbon with some other element (Webster). (2) A commercial term for calcium carbide used in miners' lamps.

Carbolic acid.—A white, crystalline, deliquescent compound, C_6H_5OH, with a burning taste and odor resembling that of creosote. It is a caustic poison (Standard).

Carbon.—An elementary substance occurring native as the diamond and also as graphite or black lead and forming a constituent of coal, petroleum, asphalt, limestone, and other carbonates, and all organic compounds. Symbol, C; atomic weight, 12.0; specific gravity, 1.7 to 3.6 (Webster).

Carbonaceous.—Coaly, containing carbon or coal. Especially shale or rock containing small particles of carbon distributed throughout the whole mass (Steel).

Carbon black.—A name for lampblack.

Carboniferous.—In the nomenclature of the U. S. Geological Survey, and in general usage as well, the youngest of the systems into which the Paleozoic stratified rocks are divided; also the corresponding period of geological time (La Forge).

Carbon oil.—A trade name for kerosene.

Carbureted hydrogen.—Any of several gaseous compounds of carbon and hydrogen, some of which are the constituents of illuminating gas (Webster). Light carbureted hydrogen is methane or marsh gas, CH_4. It is the chief constituent of fire-damp.

Car oil.—Black lubricating oils designated as low cold-test black oil, etc.

Carpet.—A bituminous surface of appreciable thickness, generally formed on top of a roadway by the application of one or more coats of bituminous material with gravel, sand, or stone chips added (Bacon).

Carry.—To run casing intermittently with drilling, without landing it (Sands).

Casing.—A term applied to steel or iron pipe used in a well to prevent caving of the walls or the ingress of water, or both (Sands).

Casing anchor packer.—A type of packer.

Casing bowl.—A fishing tool.

Casing clamps.—Instruments generally manufactured from wrought iron, and used for raising and lowering casing.

Casing dog.—In well boring, a fishing instrument provided with serrated pieces, or dogs, sliding on a wedge, to grip severed casing; also called bull dog; casing spear (National Tube Co.).

Casing elevators.—A well-boring device consisting of two semicircular clamps with a chain link on either, which are hinged together at one end and secured by a latch at the other. Used for raising and lowering casing (National Tube Co.).

Casing fitting.—A fitting threaded with a casing thread (National Tube Co.).

Casing head.—A fitting used at the top of the casing of a well, to separate oil and gas, to allow pumping and cleaning out the well, etc. It may have several lateral outlets, through which the oil is led away to reservoirs by means of pipes.

In well boring, a heavy mass of iron screwed into the top of a string of casing to take the blows produced when driving the pipe. Also called drive head (National Tube Co.).

Casing-head gas.—The trade name given to the gas which issues from the casing head of oil wells (Cooper).

Casing hook.—A heavy hook, usually attached to the traveling pulley block, which engages the links of the casing elevator (Sands).

Casing knife.—A tool for cutting off casing in the hole (Sands).

Casing ripper.—A tool containing expanding knives which can be lowered into a drill hole to cut longitudinal slits in the casing.

Casing shoe.—In well boring, a ring or ferrule of hard steel with a sharp edge, screwed or shrunk on to the bottom of a string of casing, to cut its way through the formation as the casing is forced down (National Tube Co.).

Casing spear.—See Casing dog.

Casing substitute.—A connection used in fishing with the rotary (Sands).

Casing tester.—A device used to determine the location of a leak in casing (Sands).

Catalysis.—A process described by Berzelius as a decomposition and new combination produced among the proximate and elementary principles of one or more compounds by virtue of the mere presence of a substance or substances which do not of themselves enter into the reaction (Ingalls).

Catalytic.—An agent employed in catalysis, as platinum black, aluminum chloride, etc. (Webster).

Catch-all.—A tool for extracting broken implements from drilled wells (Webster).

Cat head.—A winch head on the counter shaft of the draw works in a rotary rig (Sands).

Cave.—The partial or complete falling in of a mine or well. Also called cave-in.

Cementing.—The construction of a barrier between the exterior of the lower portion of the casing and the wall of a well, in order to exclude all water from the drill hole (Sands).

Center irons.—The iron or steel parts which make up the shaft on which the walking beam moves (Sands).

Centigrade.—Consisting of a hundred divisions. The centigrade thermometer has zero, 0°, as the freezing point of water and 100° as its boiling point. Centigrade = (° Fahrenheit − 32) $\times \frac{5}{9}$ = ° Réaumur $\times \frac{5}{4}$.

Centigram.—A weight equal to one hundredth part of a gram or 0.15432 of a grain. See also Gram (Webster).

Centrifuge.—An instrument for separating liquids of different specific gravities by use of centrifugal force (Delbridge).

Centrifuge stock.—This name is obtained from the rapid centrifugal method of separation. The wax obtained from the process is of somewhat higher melting point than that obtained simply by cold settling (A. D. Smith).

Centrifugal force.—A force directed outward when any body is constrained to move in a curved path; flying away from the center (Webster).

Centroclinical.—(Geology.) An uplift of strata which gives them a partial quaquaversal dip (Webster).

Ceresin.—A substitute for beeswax, prepared by heating ozokerite with sulphuric acid, with constant stirring, and decolorizing with charcoal; the product is then treated with volatile solvents to extract the contained ceresin.

Chain.—(Chemistry.) A number of atoms united serially (Webster).

Chain tongs.—A pipe-fitter's tool; a lever with a serrated end provided with a chain to enlace the pipe. The chain is wrapped around the pipe to hold the lever in place, and the teeth on the end of the latter grip into the pipe, thus affording a powerful leverage to screw or unscrew the joints (National Tube Co.).

Chalk rock.—Driller's term for soft white limestone, diatomaceous shale, etc.

Check valve.—An automatic non-return valve; or a valve which permits a fluid to pass in one direction, but automatically closes when the fluid attempts to pass in the opposite direction (National Tube Co.).

Cheesebox.—A vertical cylindrical still, used in the distillation of kerosene.

Chemistry.—The science that treats of the composition of substances and of the transformations which they undergo. There are two main groups: (*a*) organic chemistry, which treats of the hydrocarbons and their derivatives; and (*b*) inorganic chemistry which treats all other compounds, and of the elements (Webster).

Cherry picker.—A fishing tool.

Chert.—A form of amorphous silica (SiO_2).

Chromometer.—An instrument for determining the color of petroleum and other oils (Standard). See Colorimeter.

Churn drill—Also called cable drill or well drill. Applied to a stationary drill operated from a derrick as in oil-well drilling. Also portable drilling equipment, usually mounted on four wheels and driven by gasoline, electricity, or steam. The drill head is raised by means of a rope or cable and allowed to drop, thus striking successive blows by means of which the rock is pulverized and the hole deepened (Bowles).

Circular polarization.—A phenomenon observed in a polariscope when two-plane-polarized rays, propagated in the same direction, have their vibration directions at right angles to each other and differ by one-quarter of a wave-length in phase (Dana).

Circulation.—Passing water, with or without mud, through a rotary bore-hole.

Claroline.—A mineral oil used as a solvent for natural gases.

Clay revivifying system.—A method by which fullers' earth or other decolorizing clays are cleaned for re-use (A. D. Smith).

Clay wash.—Method used to improve color or odor of an oil by agitating the oil with fullers' earth or other clay.

Cleavage.—(Petrology.) A tendency to cleave or split along definite, parallel, closely spaced planes, which may be highly inclined to the bedding planes. It is a secondary structure, commonly confined to bedded rocks. It is developed by at least some recrystallization of the rock (La Forge). The term cleavage should not be applied to the fracturing of rocks, which is jointing.

Clinch, or clink bolts.—Cross bolts under spear bolts to prevent the pump rods from stripping (G. C. Greenwell).

Clinometer.—An instrument used to measure vertical angles, such as the dip of strata or the slope of the ground (Lahee).

Closed basin.—A district draining to some depression or lake within its area, from which water escapes only by evaporation (Webster).

Closed fold.—A fold in which the limbs (sides of the arch) have been compressed until they are parallel (Farrell).

Close nipple.—One whose length is about twice the length of a standard pipe thread and is without any shoulder (National Tube Co.)

Close return bend.—A short, cast or malleable iron, U-shaped fitting for uniting two parallel pipes. It differs from the open return bend in having the arms joined together (National Tube Co.).

Close sand.—Sand that is too closely grained to form a good oil reservoir.

Cloud test.—The temperature at which paraffin waxes or other solid substances begin to crystallize out or separate from solution when an oil is chilled under definite specified conditions (Delbridge).

Coal.—A carbonaceous substance formed by the remains of vegetation by partial decomposition (U. S. Geol. Survey). A solid and more or less distinctly stratified carbonaceous substance varying in color from dark brown to black; brittle, combustible, and used as a fuel; not fusible without decomposition and very insoluble. In its formation, the vegetal matter appears to have first taken the form of peat, then lignite, and finally bituminous coal. The latter, by the loss of its bitumen, has in some places been converted into anthracite or hard coal. Lignite gives a brown powder, coal a black. Lignites contain a large percentage of water and ash (Fay).

Coal gas.—Gas made from coal by distilling bituminous coal in retorts, and used for lighting and heat (Webster).

Coal oil.—The crude oil obtained by the destructive distillation of bituminous coal; that distillate, obtained from such a crude oil, which may be used for illuminating purposes; kerosene, crude petroleum (Bacon).

Coal tar.—The mixture of tar distillates produced in the destructive distillation of coal. The hydrocarbons contained in raw coal-tar are chiefly unsaturated ring compounds. The tar contains also light oils, pyridine bases, phenols, etc.

Coal-tar naphtha.—The light oil produced in the distillation of coal tar.

Coal-tar pitch.—The residuum from the distillation of coal tar.

Coating for pipe.—Usually a coal-tar composition sometimes called asphalt (National Tube Co.).

Cock.—A device for regulating or stopping the flow in a pipe, made by a taper plug that may be rotated in a body having ports corresponding to those in the plug (National Tube Co.).

Coefficient.—(Physics.) A number commonly used in computations as a factor, expressing the amount of some change or effect under certain conditions as to temperature, length, time, volume, etc., as the coefficient of contraction, depression, discharge, displacement, efficiency, etc.

Cofferdam.—A double bulkhead, provided in tank steamers for the purpose of isolating the oil cargo from the engine and boiler space or from the holds used for other cargo, and to prevent leakage into the adjacent compartments (Mitzakis).

Cohesion.—That force by which molecules of the same kind or of the same body are held together, so that the body resists being pulled to pieces (Rickard).

Coil.—A number of turns of piping or series of connected pipes in rows or layers for the purpose of radiating or absorbing heat (National Tube Co.).

Coil drag.—A tool to pick up pebbles, bits of iron, etc., from the bottom of a drill hole (Raymond).

Coke.—Bituminous coal from which the volatile constituents have been driven off by heat, so that the fixed carbon and the ash are fused together. Commonly artificial; but natural coke is also known (U. S. Geol. Survey). See also Petroleum coke.

Coke-oven tar.—Coal tar produced in by-product coke ovens in the manufacture of coke from bituminous coal.

Coke scrubber.—An apparatus filled with coke moistened with oil, used to purify gases.

Coking.—The process of distilling to dryness a petroleum product containing complex hydrocarbons that break down in structure during distillation; usually applied to the dry distillation of tar or crude when an appreciable layer of carbon (coke) is formed on the bottom of the still (A. D. Smith).

Cold-pressing or "pressing."—The separation by filtration of a solid Petroleum product from a liquid petroleum medium in a standard type of filter press. The term pressing, in its usual application, refers to the separation of paraffin wax from some form of lubricating distillate (A. D. Smith).

Cold-settling.—The separation, by virtue of difference in specific gravity, of a petroleum product, solid at the temperature employed, from an enveloping liquid petroleum medium. In its usual application, the term refers to the separation of amorphous wax at low temperature from a naphtha solution of filtered steam-refined stock (A. D. Smith).

Cold test.—A name given to a test applied to lubricating oils in order to ascertain their power of withstanding low temperatures without solidifying or depositing paraffin (Mitzakis).

Collar.—(1) A term used in place of the word coupling, in such connections as "Kimberley Collars." Also used to mean threaded pipe coupling (National Tube Co.).

(2) The sleeve in the back of certain styles of flanges, such as a riveted flange, is called a collar (National Tube Co.).

(3) Again, certain styles of flanges attached by peening and beading are known as "Collar Flanges" (National Tube Co.).

Collar buster.—A fishing tool used to part a string of casing above the point at which it is frozen (Sands).

Collar flange.—One having sufficient collar on its back to allow it to be securely attached to pipe by peening or riveting (National Tube Co.).

Colloid.—A term describing a state of matter supposed to represent a degree of subdivision into almost molecular dimensions. Colloidal particles possess the property of carrying electric charges, and also of failing to diffuse through a membrane, this being the original distinction between colloids and crystalloids.

Colophony.—See Rosin.

Colorimeter.—An instrument for determining the color of petroleum, as compared to water.

Comanche series.—The Lower Cretaceous series of limestones covering most of Texas.

Combination gas.—Natural gas rich in oil vapors; wet gas. Also called casing-head gas (Fay).

Combination rig.—A rig comprising a complete cable-tool outfit and a complete rotary outfit (Sands).

Combination socket.—A fishing tool (Sands).

Combining weight.—That proportional weight, referred to some standard, and for each element fixed and exact, by which an element unites with another to form a distinct compound. The combining weights are either identical with, or are some multiples or sub-multiples of, the atomic weight (Webster).

Combustible.—Capable of undergoing combustion; inflammable (Webster).

Combustion.—The act or process of burning. Chemically considered, it is a process of rapid oxidation caused by the union of the oxygen of the air, which is the supporter of combustion, with any material that is capable of oxidation (Century).

Combustion chamber.—A space over or in front of a furnace, where the gases from the fire become more thoroughly mixed and burnt (Webster).

Combustion method.—A method for the quantitative determination of carbon, hydrogen, etc., by combustion of the substance with air, oxygen, or some solid oxidizing material, as copper oxide, and absorption or collection of gaseous products. It

is extensively used for the analysis or organic compounds, and also for the determination of carbon in iron and steel (Webster).

Combustion tube.—A tube capable of standing considerable heat, used in the combustion method (Webster).

Compass.—An instrument for determining directions, usually by the pointing of a magnetic needle free to turn in a horizontal plane, as, for example, the ordinary surveyor's compass.

Composition.—An aggregate, mixture, mass, or body formed by combining two or more substances; a composite substance (Webster). The chemical constitution of a rock or mineral (Power).

Compound.—(1) A distinct substance formed by the union of two or more ingredients in definite proportions by weight. To be distinguished from a mixture (Webster).

(2) A lubricant applied to the inside and outside of ropes, preventing corrosion and lessening abrasion of the rope when in contact with hard surfaces (C. M. P.).

Compound oils.—Mineral oils which are mixed with animal or vegetable oils to increase viscosity or adhesion.

Conchoidal.—Having shell-shaped depressions or elevations. Thus, a rock breaks with a conchoidal fracture when the faces made by such fracture are irregularly concave or convex.

Condenser.—An apparatus for liquefying vapors by cooling only.

Conduction.—Transmission through, or by means of, a conductor. Distinguished, in the case of heat, from convection and radiation (Webster).

Conductor.—In drilling, the first string of casing (Sands).

Cone rock-bit.—A rotary drill, composed of two hardened steel cones, used in hard rock (Sands).

Conformable.—When beds or strata lie upon one another in unbroken and parallel order, and this arrangement shows that no disturbance has taken place at the locality while their deposition was going on, they are said to be conformable. But if one set of beds rests upon the eroded or the upturned edges of another, showing a change of conditions or a break between the formations of the two sets of rocks, they are said to be unconformable (Roy. Com.).

Conglomerate.—An aggregate of rounded and water-worn pebbles and bowlders cemented together into a coherent rock (Kemp). It is deposited by streams or waves, generally with some sorting and stratification.

Connate water.—Water which was deposited simultaneously with the deposition of solid sediments, and which has not, since its deposition, existed as surface water or atmospheric moisture (Meinzer).

Conservation.—A conserving, preserving, guarding, or protecting; a keeping in a safe or entire state; preservation, as of mineral resources.

The best definition is that of C. W. Hayes: The maximum efficiency with minimum waste in the production of unrenewable resources.

Consistency.—The degree of solidity or fluidity of bituminous materials (Fay).

Contact process.—A process for the manufacture of sulphuric acid, based on the catalytic action of finely divided platinum. It is conducted by passing the well-dried and purified burner gases through the contact apparatus, at a temperature of 350° C. and absorbing the sulphur trioxide, formed by the direct union of sulphur dioxide and oxygen, in water (Webster).

Continuous process of distillation.—A petroleum distillation process in which the crude oil flows slowly by gravitation through a series of stills or retorts each placed

slightly lower than the preceding one. Each still has a carefully maintained temperature, and yields, therefore, continuously a product of given volatility (Mitzakis).

Contour.—In mapping, a line which joins points of equal elevation above sea level. A synonym for relief.

Contour interval.—The difference in elevation between two contours. It may be any chosen quantity; but must be the same on all parts of any particular map. Small intervals are employed when bed dips gently, but if bed dips several hundred feet to the mile, a large interval is used.

Contour map.—Map showing, by use of curved lines or contours, supposed to be drawn on the top or bottom surface of some definite stratum or key bed, the elevation, the sketch showing these lines as they would appear if viewed from above.

Control.—In geologic field mapping, a system of stations, the positions of which have been established so that they may serve as a guide in the location of subsequent stations or in the plotting of geologic features (Lahee).

Control casing head.—A casing head equipped with valves or gates by which an unexpected flow of oil may be diverted into flow lines either with or without withdrawing the tools.

Convection.—A process of transmission, as of heat, by means of currents in liquids or gases, resulting from changes of temperature or other causes (Webster).

Converse lock joint.—A joint, for wrought pipe, that is made up with a cast-iron hub (National Tube Co.).

Conveyer; conveyor.—One who or that which conveys, transports, or transfers; specifically, any mechanical contrivance for conveying material in the working of mills, elevators, etc., such as endless chains, etc. (Standard).

Cooker.—A lead-lined vat in which the original separation of sludge acid is carried out (A. D. Smith).

Cordage.—A term applied to both fiber and steel wire rope used in drilling (Sands).

Core.—A cylinder-shaped piece of rock produced by a core-drill (Steel). The central part of a rope, forming a cushion for the strands. In wire ropes it is sometimes made of wire, but usually it is of hemp, jute, or some like material (C. M. P.).

Core bit.—A hollow cylindrical boring bit for cutting out a core in earth boring or rock drilling (Webster). In operation it is attached to and forms part of the core drill.

Core drill.—A diamond or other hollow drill for securing cores (C. M. P.). See also Diamond drill, Adamantine drill, Shot drill, and Calyx.

Core lifter.—An instrument used to bring up the cores left by an annular bit in a boring (Standard).

Correction curve.—A chart which shows how much should be added to or subtracted from an observation to arrive at a standard reading; as to barometric readings to obtain the true elevation. See Diurnal pressure variation.

Correlate.—To connect by the disclosure of mutual relation (Webster). Thus, to determine the continuity of a series of strata over a considerable area.

Correlation.—The determination of the equivalence in geologic age and stratigraphic position of two formations or other stratigraphic units in separated areas; or, more broadly, the determination of the contemporaneity of events in the geologic history of two areas. Fossils constitute the chief evidence in problems of correlation (La Forge).

Corrosion.—The process of wearing away, disintegrating or destroying by the gradual separation of small parts of particles, especially by the action of chemical agents, as an acid (Century).

Corrosion and gumming test.—The quantity of tarry residue remaining, and the discoloration of the copper cup resulting from the complete evaporation of gasoline under standard laboratory conditions (Delbridge).

Corrugated friction socket.—A fishing tool.

Counter-current pipe exchanger.—A heat exchanger, constructed of pipe, in which the direction of the cold oil is opposite to that of the hot oil (A. D. Smith).

Countersink.—(1) A tool used to chamfer the mouth of a hole.

(2) The operation that uses a countersink tool (National Tube Co.).

Countersunk.—(1) Having the shape given by the use of a countersink.

(2) Also applied to a certain type of plug which has an opening depressed to receive a square wrench.

(3) When applied to fittings it means chamfered at an angle of 45° at the tapped opening (National Tube Co.).

Coupling..A threaded sleeve used to connect two pipes (National Tube Co.). A device for joining two rope-ends without splicing (C. M. P.).

Cow sucker.—A heavy piece of iron attached to the end of the drilling cable in order to facilitate the descent of the latter when the tools are disconnected (Mitzakis).

Cracker.—A length (usually about 100 feet) of manila cable inserted between the tools and the wire line to furnish the desired elasticity (Sands).

Cracking.—The art of producing low-boiling-point hydrocarbons suitable for motor fuel, in commercial quantities, from distillates or residua of high molecular weight (A. D. Smith). It originated about fifty years ago among stillmen in the old Pennsylvania refineries and means just what its connotation conveys, namely, a partial alteration, as distinguished from the more complete decomposition which would disrupt the molecule largely into carbon and permanent gas. Cracking simply alters the molecules to an extent that produces an amount of low-boiling fractions that cannot be obtained by simple distillation. It may not be accompanied by any considerable production of permanent gas, the product being largely a liquid condensate, but of different character from that obtained by simple distillation (Min. and Sci. Press).

Creosote.—(1) An oily antiseptic fluid obtained by the distillation of wood tar. Also a similar substance obtained from coal tar.

(2) To saturate or impregnate with creosote, as timber, to prevent decay (Webster).

Cretaceous.—The third and latest of the periods included in the Mesozoic era; also the system of strata deposited in the Cretaceous period (La Forge).

Crevice oil.—Oil occurring in shale, as in the Florence, Colorado, oil field. Sometimes erroneously called shale oil.

Critical density.—The density of a substance at its critical point (Fay).

Critical pressure.—The pressure necessary to raise the boiling point of a substance, in the liquid state, to the critical temperature; the pressure that will just liquefy a gas at its critical temperature (Webster).

Critical temperature.—Any temperature marked by a transition; the temperature above which a substance can exist only in the gaseous state, no matter what the pressure (Webster).

Crop out.—To be exposed at the surface; referring to strata (Whitney). See Outcrop.

Cropping out.—The natural exposure of bedrock at the surface. That part of a vein which appears at the surface is called the cropping or outcrop (Raymond).

Croppings.—Portions of a vein or bed as seen exposed at the surface.

Cross.—A pipe-fitting with four branches arranged in pairs, each pair on one axis and the axes at right angles. When the outlets are otherwise arranged the fittings are branch pipes or specials (National Tube Co.).

Cross-anticline.—See Anticlinal bulges.

Cross-bedded.—Characterized by minor beds or laminæ oblique to the main stratification; cross-stratified (Webster).

Cross-bedding.—Lamination, in sedimentary rocks, confined to single beds and inclined to the general stratification (La Forge). Caused by swift, local currents, deltas, or swirling wind-gusts and especially characteristic of sandstones, both aqueous and aeolian (Kemp).

Cross-over.—A small fitting like a double offset or the letter "U," with ends turned out. It is only made in small sizes and used to pass the flow of one pipe past another when the pipes are in the same plane (National Tube Co.).

Cross-over tee.—A fitting made along lines similar to the cross-over, but having at one end two openings in a tee head whose plane is at right angles to the plane of the cross-over bend (National Tube Co.).

Cross-stratification.—(Geology.) The condition of having the minor laminations oblique to the plane of the main stratum which they help to compose (Standard). See Cross-bedding.

Crown block.—The group of timbers at the top of a derrick which support the bearings for the various pulleys.

Crown pulley.—The pulley at the top of the derrick over which the drilling line passes (Sands).

Crown sheets.—The upper steel plates in an oil still (A. D. Smith).

Crude.—A name for unrefined petroleum. In a natural state; not altered, refined, or prepared for use by any process, as crude ore (Webster).

Crude mineral oil.—A name for petroleum.

Crude naphtha.—Unrefined petroleum naphtha (Standard).

Crude oil.—Petroleum.

Crystalloid.—A substance which, in solution, diffuses readily through animal membranes, lowers the freezing point of the solvent, and generally is capable of being crystallized. Opposed to colloid (Webster). Metallic salts, sugar and oxalic acid are crystalloids.

Curly shale.—A Pumpherston oil-shale. Any folded or distorted oil-shale.

Cuts.—Divisions of petroleum distillate according to temperature, gravity, or percentage of the amount distilled.

Cut-back products.—Petroleum or tar residua which have been fluxed, each with its own or similar distillates (Bacon).

Cyclic.—A term applied to certain hydrocarbons, the properties of which are best explained by the assumption that some of the atoms of carbon are connected in a ring; or in several rings—polycyclic.

Cymogene.—The lightest commercial product obtained from petroleum. It finds use as a local anesthetic and is also employed in certain types of refrigerating machines (A. D. Smith).

Dead end.—The closed end of a pipe or system of pipes (National Tube Co.).

Dead oil.—A name given to those products of distillation consisting of carbolic acid, naphthalene, etc., obtained in the distillation of coal tar, which are heavier than water and which come off at about 340° F., or over (Century).

Deadwood.—Roof or coil supports, swing-pipes, etc.; any permanent material in a tank that displaces volume (A. D. Smith).

Deblooming agents.—Mono-nitronaphthalene and yellow coal-tar dyes sometimes added to mineral oils to mask the fluorescence (Bacon).

Declination.—The angle which the magnetic needle makes with the geographical meridian.

Decolorizing.—The process of removing suspended, colloidal, and dissolved impurities from liquid petroleum products by filtering, adsorption, acid treatment or redistillation.

Decomposition.—The breaking up of compounds into simpler chemical forms.

Deep-well pump.—A pump for oil wells, etc. (Standard).

Definite proportions law.—The fundamental chemical law that a chemical compound always contains the same elements in the same proportions by weight (Liddell).

Degree.—A division, space, or interval marked on a mathematical or other instrument, as on a thermometer (Webster).

Dehydrate.—To render free from water (Webster).

Dehydrator.—An apparatus in which water is removed from oil. This may be accomplished (1) by settling and gravitational separation, (2) by centrifugal separation, (3) by boiling off the water, (4) by electric currents of high voltage which break down the emulsion and permit gravitational settling.

Densimeter.—An apparatus for determining the specific gravity or relative density of a substance (Standard).

Density.—The ratio of the mass of any volume of a substance to the mass of an equal volume of some standard substance. For liquids and solids the standard substance is water (Webster).

Dephlegmator.—A column or tower provided with baffles or surface contact in the shape of rings, crocks, stones, etc.; an apparatus for securing more complete separation of products than is possible in simple distillation (A. D. Smith).

Depletion.—The act of emptying, reducing or exhausting, as the depletion of natural resources (Century).

Deposit.—Anything laid down. Formerly applied to suspended matter left by the agency of water, but now made to include also mineral matter in any form, and precipitated by chemical or other agencies, as the ores, etc., in veins (Winchell).

Derrick.—The framework or tower over a deep drill hole, such as that of an oil well, for supporting the tackle for boring, hoisting or lowering. Any of various hoisting apparatus employing a tackle rigged at the end of a spar or beam (Webster).

Desiccated.—Dried to a powdery or granular condition.

Destructive distillation.—The process of heating an organic compound in a closed vessel, without access of air, and collecting the products (Nicholls). A process of distillation in which hydrocarbon molecules are broken down. Thus, illuminating gas is a product of the destructive distillation of coal. Also called dry distillation and cracking.

Detritus.—The product of the wear or erosion of rocks.

Devonian.—The fourth, in order of age, of the periods comprised in the Paleozoic era, following the Silurian and succeeded by the Carboniferous. Also the system of strata deposited at that time (La Forge).

Diaclinal.—Crossing a fold, as a diaclinal river (Webster).

Dialysis.—The separation of crystalloids and colloids in solution, by means of their unequal diffusion through certain natural or artificial membranes (Webster).

Diamond drill.—A form of rotary rock-drill in which the work is done by abrasion instead of percussion, black diamonds (borts) being set in the head of the boring tool (Raymond). Used in prospecting and development work where a core is desired.

Diastrophism.—The process or processes by which the crust of the earth is deformed, producing continents and ocean basins, plateaus and mountains, flexures, folds, and faults. Also the result of these processes (Webster).

Diatom.—A minute plant provided with a siliceous envelope (Duryee).

Diatomaceous shale.—Bedded rock composed of the siliceous skeletons of diatoms.

Die.—The name of a tool used for cutting threads, usually at one passage. The essential distinctive feature of a die is its multiple cutting edges, while a chasing or threading tool usually has one, or at most, only a few cutting edges (National Tube Co.).

Die nipple.—A tool used in recovering drill pipe. It acts as a die, cutting threads on the lost pipe.

Diesel engine.—The engine invented by Dr. Rudolf Diesel, the important features of which are its adherence to the principle of the Carnot cycle and the elimination of any means of ignition other than the pressure generated in the engine cylinder (Goldingham). An internal combustion engine in which only air is drawn in by the suction stroke, and the air is so highly compressed that the heat generated ignites the fuel which is automatically sprayed into the cylinder under high pressure (Webster).

Diffusate.—(Chemistry.) Material which, in the process of dialysis, has diffused or passed through the separating membrane (Webster).

Dike.—A long and relatively thin body of igneous rock, which, while in a state of fusion, has entered a fissure in older rocks and has there chilled and solidified (Century).

Diluent.—That which dilutes, or makes more fluid; a fluid that weakens the strength or consistence of another fluid upon mixture (Century).

Dip.—The angle at which beds or strata are inclined from the horizontal.

Dip-arrow map.—Crude type of map used in rapid field work with the object of indicating the approximate position of structures; used to record results of reconnaissance work.

Dip pipe.—A valve in a gas main, so arranged as to dip into water and tar, and thus form a seal. Called also a seal pipe (National Tube Co.).

Dip slip.—See under Displacement, normal.

Dip slope.—The slope of an escarpment in the direction of the dip of the beds which form the escarpment.

Dip throw.—The component of the slip measured parallel with the dip of the strata (Lindgren).

Direction of strata.—The strike, or line of bearing. (Hitchcock).

Discovery.—The first finding of a mineral deposit, including petroleum, in place upon a mining claim. A discovery is necessary before the location can be held by a valid title. The opening by which it is made is called discovery-shaft, discovery-tunnel, etc. (Raymond). The finding of a mineral in place, as distinguished from float rock, constitutes a discovery (Book *vs.* Justice Mining Co., 158 Fed. Rept., p. 120; Nevada Sierra Oil Co. *vs.* Home Oil Co., 98 Fed. Rept., p. 676; Shoshone Mining Co. *vs.* Rutter, 87 Fed. Rept., p. 807; Migeon *vs.* Montana, etc., R. Co., 77 Fed. Rept., p. 249; McShane *vs.* Kenkle, 18 Montana, p. 208; 44 Pacific, p. 979; U. S. Min. Stat., p. 23; pp. 66–70).

Disintegration.—The breaking asunder and crumbling away of a rock, due to the action of moisture, heat, frost, air, and the internal chemical reaction of the component parts of rock when acted upon by these surface influences (Roy. Com.).

Dispersoid.—A body that has been dispersed in a liquid (Rickard).

Displacement, horizontal.—A term used by Tollman to designate Strike slip, See Fault (Lindgren).

Displacement, normal.—A term used by Tollman to designate Dip slip, See Fault (Lindgren).

Displacement, total.—A term used by Spurr and Tollman to designate Slip, See Fault (Lindgren).

Dissociate.—(Chemistry.) To resolve, through variation of some physical condition, into simpler substances that are capable of reuniting to form an original one (Century).

Dissociation.—The act or process consisting in the reversible resolution or decomposition of substances with complex molecules into those with simpler ones, when produced by a variation in physical conditions; also the state resulting from such process (Century).

Distillate.—(1) The product of distillation, as petroleum distillate.

(2) The product of distillation intermediate between gasoline and lubricating stock, including kerosene and gas oil.

Distillation.—Volatilization, followed by condensation to the liquid state (Raymond).

Distillation loss.—In a standard laboratory distillation, the difference between the volume of liquid originally introduced into the distilling flask and the sum of the recovery and the residue (Delbridge).

Distilling or stilling.—The separation by volatilization of one group of petroleum constituents from another, in some form of closed apparatus, by the aid of directly or indirectly applied heat (A. D. Smith).

Disturbance.—The bending or faulting of a rock or stratum from its original position (Roy. Com.).

Diurnal pressure variation.—The daily fluctuation of the aneroid barometer at a given spot.

Divining rod.—A rod (most frequently of witch-hazel, and forked in shape) used, according to an old, but still extant superstition, for discovering mineral veins and springs of water, and even for locating oil wells (Raymond).

Doctor solution.—An aqueous solution of sodium plumbite and sodium hydroxide used in making the doctor test (Delbridge).

Doctor test.—A qualitative method of detecting undesirable sulphur compounds in petroleum distillates (Delbridge).

Dog.—See Casing dog.

Dog legs.—In drilling, a term applied to short bends in wire cable (Sands).

Dome.—(Geology.) An uplift in which the beds dip outward in all directions from a center (Webster). Oil and gas pools are frequently found beneath domes.

Double core-barrel drill.—A core drill having an inner tube that is suspended on ball bearings and thus may remain still while the outer tube revolves. It is designed to bring out a core from a delicate material with a minimum of breaking or other damage (Bowles).

Double extra strong.—The correct term or name for a certain class of very thick pipe, which is often, less correctly, called double extra heavy pipe (National Tube Co.).

Double sweep tee.—A tee made with easy curves between body and branch, *i.e.*, the center of curve between run and branch lies outside the body. This is in contradistinction to the short fillet between body and branch of standard tees (National Tube Co.).

Drainage fittings.—Fittings that have their interior flush with I.D. of pipe, thereby securing an unobstructed surface for the passage of solid matter (National Tube Co.).

Draw works.—A counter-shaft and drum substituted in rotary drilling for the bank wheel, calf wheel, bull wheel and sand reel used in the cable-tool method.

Dress.—In drilling, to sharpen the bit and to bring it to the required diameter of gage (Sands).

Dresser joint.—A peculiar form of Normandy joint. There are various styles (National Tube Co.).

Drill.—(1) A metallic tool for boring in hard material. The ordinary miner's drill is a steel bar with a chisel-shaped end, and is struck with a hammer. See Rock drill. See Diamond drill (Raymond).

(2) To make a hole with a drill or a similar tool. See Drilling, as applied to oil and gas wells.

Drill core.—A solid, cylindrical core of rock cut out by a diamond or shot drill. It forms a record of the strata penetrated.

Driller.—One who, or that which, drills. A drilling machine.

Drill extractor.—A device for withdrawing the drill bit from wells; drill tongs (Standard).

Drilling.—A term employed in a general way to denote the different processes employed for the discovery and extraction of petroleum or natural gas. Two general methods of drilling have come to be recognized: (*a*) Percussion systems, which consist of breaking up the ground by means of a sharp-pointed instrument of a particular form, which is made to strike the ground in a series of blows; (*b*) Rotary systems, which permit all the disintegrated material to be washed away, or aim at the extraction of a core. The English term is " boring."

Drilling jars.—Jars with a short stroke, usually placed above the auger stem in a string of tools; used to impart a sharp blow in dislodging the tools (Sands).

Drill pipe.—The pipe used as auger stem in drilling a rotary well (Sands).

Drill rod.—A vertical rod bearing a drilling tool, for boring wells (Standard).

Drip.—A name given to an apparatus attached to natural-gas wells to extract from the mains any liquid, such as oil or water, that may accompany the gas. It usually consists of four iron tubes placed vertically, the inner two being connected by a cross tube. During the passage of the gas through this apparatus, the liquid becomes separated and accumulates in a tube called a tail piece, from which it is

blown out from time to time (Mitzakis). Any opening arranged to take a liquid from a line carrying gas, as in condensation from a steam line.

Drips.—Filter drainings too dark in color to be included in filtered stock. They are set aside for charging into the next filter in succession (A. D. Smith).

Driven well.—A well which is sunk by driving a casing at the end of which there is a drive-point, without the aid of any boring, jetting or drilling device (Meinzer).

Drive-pipe.—A pipe which is driven or forced into a bored hole, to shut off water or prevent caving (National Tube Co.). A thick tube or casing fitted at its lower end with a sharp steel shoe, which is employed when heavy driving has to be resorted to for inserting the casing (Mitzakis).

Drive-pipe ring.—A device for holding the drive-pipe while it is being pulled from a well (National Tube Co.).

Drive shoe.—A protecting end attached to the bottom of drive-pipe and casing (National Tube Co.).

Driving cap.—A cap of iron fitted to the top of a pipe, as in an oil well, to receive the blow when driven and thus protect the pipe (Fay).

Drowned.—A term describing the condition of a well when water is present in large enough quantities to make production unprofitable, or when the water actually forces back the oil in the producing horizon (Sands).

Drum.—(1) That part of the winding machinery on which the rope or chain is coiled (Raymond).

(2) A metal cask for the shipment of oil, gasoline, etc.

Drum rings.—Cast-iron wheels, with projections, to which are bolted the staves or laggings forming the surface for the hoisting cable to wind upon. The outside rings are flanged to prevent the cable from slipping off the drum (Gresley).

Dry distillation.—See Destructive distillation.

Dry gas.—Natural gas obtained from sands that produce gas only. It does not contain an appreciable amount of gasoline.

Dry hole.—A well in which no oil or gas is found.

Dry sand.—A stratum of dry sand or sandstone encountered in well drilling. A non-productive sandstone in oil-fields.

Dual system.—A rig which has only sufficient cable tools and machinery to complete the well and drill into the sand after the rotary. Also called standard tool drilling-in outfit (Sands).

Duriron.—An acid-resisting alloy used for making evaporating dishes in recovering sulphuric acid from sludge. It consists of 14 to 14.5 per cent silicon, 0.25 to 0.35 per cent manganese, 0.2 to 0.6 per cent carbon, 0.16 to 0.2 per cent phosphorus, and under 0.05 per cent sulphur, the remainder being iron. Its melting point is from 2500° to 2550° F. The specific gravity is 7 (Min. and Sci. Press).

Duster.—An unproductive boring for oil or gas.

Dust-laying oils.—Crude oils, heavy asphalt oils, tars, solutions of petroleum asphalt in gas oils, liquid asphalt, and emulsions of oils and water, used for laying dust on roads (Bacon).

Earth.—(1) The solid matter of the globe as distinguished from water and air; the ground; the firm land of the earth's surface.

(2) The disintegrated particles of solid matter as distinguished from rock; soil; loose material of the earth's surface.

(3) (Chemistry.) Metallic oxides of the calcium group.

Earth oil.—Petroleum (Webster).

Easement.—The rights of entry, etc., necessary for developing the enterprise in question.

Eccentric bit.—A modified form of chisel used in drilling, in which one end of the cutting edge is extended farther from the center of the bit than the other. The eccentric bit renders under-reaming unnecessary. It is very useful in hard rock (Mitzakis).

Edge water.—In oil and gas wells, water that holds the oil and gas in the higher structural positions. Edge water usually encroaches on a field after much of the oil and gas has been recovered and the pressure has become greatly reduced. Compare Top water; Bottom water (U. S. Geol. Survey Bull. 658, p. 44).

Eduction pipe.—The exhaust pipe from a low-pressure cylinder to the condenser (National Tube Co.).

Elaterite.—A massive amorphous dark-brown hydrocarbon ranging from soft and elastic to hard and brittle. It melts in a candle flame without decrepitation, has a conchoidal fracture and gives a brown streak. See also Wurtzilite (U. S. Geol. Survey). Elastic bitumen.

Elbow, ell.—A fitting that makes an angle between adjacent pipes. The angle is always 90°, unless another angle is stated (National Tube Co.)

Electrolysis.—Act or process of chemical decomposition by the action of an electric current.

Electrolyte.—(1) The solution in which electrolytic separation of metals is carried on (Weed).

(2) A chemical compound which can be decomposed by an electric current (Standard).

Elevation of a point.—The vertical distance of the point above mean sea level.

Elevator.—A device for raising or lowering tubing, casing, or drive pipe, from or into a well. See Casing elevator (National Tube Co.).

Emanations.—Gaseous discharges.

Emulsification.—The act of making or causing an emulsion.

Emulsification test.—A test conducted for the purpose of obtaining information in the laboratory as to the emulsifying tendency of oils under service conditions (Delbridge).

Emulsion.—A liquid mixture in which a fatty or resinous substance is suspended in minute particles, almost equivalent to molecular dispersion (Fay). A combination of water and oily material made miscible with water through the action of a saponifying or other agent (Bacon).

Endosmosis.—The transmission of a fluid inward through a porous septum or partition which separates it from another fluid of different density. Opposed to exosmosis (Century).

Endothermic.—Pertaining to a chemical reaction which occurs with absorption of heat (Webster).

End point or maximum temperature.—The highest temperature indicated on the distillation thermometer during standard laboratory distillation (Delbridge).

Eocene.—The earliest of the epochs into which the Tertiary period is divided; also the series of strata deposited at that time (La Forge).

Eolian.—See Aeolian.

Erosion.—The group of processes whereby earthy or rock material is loosened or dissolved and removed from any part of the earth's surface. It includes the proc-

esses of weathering, solution, corrosion, and transportation. The mechanical wear and transportation are effected by running water, waves, moving ice, or winds, which use rock fragments to pound or grind other rocks to powder or sand (Ransome).

Escarpment or scarp.—A cliff or relatively steep slope separating level or gently sloping tracts. **Scarp**: cliff or steep slope along the margin of a plateau, mesa, terrace or bench. The term should not be used for a cliff or slope of highly irregular outline (La Forge).

Ether.—(1) A hypothetical medium of extreme elasticity and supposed to be diffused throughout all space as well as among the molecules of which solid bodies are composed and to be the medium of the transmission of light and heat.

(2) A highly volatile, inflammable, light, mobile, colorless liquid used as an anesthetic and solvent (Century).

Ethylene.—A colorless gas (C_2H_4), first member of the unsaturated C_nH_{2n} series of hydrocarbons. It has a sweetish odor and taste and is a frequent product of destructive distillation. It burns with a highly luminous flame. Often called olefiant gas or heavy carbureted hydrogen.

Eudiometer.—An instrument for the volumetric measurement and analysis of gases (Webster).

Evaporate.—To convert into vapor, usually by means of heat; to vaporize; also, to remove and dissipate by this process (Standard).

Evaporation test.—A test applied to volatile petroleum products to determine the completeness or rapidity of evaporation (Delbridge).

Exhaustion.—(Chemistry.) The process of completely extracting from a substance whatever is removable by a given solvent (Century).

Exosmosis.—See Endosmosis.

Exothermic.—Pertaining to a chemical reaction which occurs with the evolution of heat (Webster).

Expander.—A device for expanding the end of a tube, in a tube-plate or casing in a well (Fay).

Expansion bit.—A drill bit that may be adjusted for holes of various sizes (Fay).

Expansion joint.—A device used in connecting up long lines of pipe, etc., to permit linear expansion or contraction as the temperature rises or falls (National Tube Co.).

Expansion loop.—Either a bend, like the letter " U," or a coil in a line of pipe to provide for expansion or contraction (National Tube Co.).

Expansion ring.—The hoop or ring of U-section used to join lengths of pipe so as to permit expansion (National Tube Co.).

Exploitation.—The extraction and utilization of minerals. Often confused with exploration (Fay).

Exploration.—The work involved in looking for or measuring mineral deposits.

Explosive.—Any mixture or chemical compound by whose decomposition or combustion gas is generated with such rapidity that it can be used for blasting or in firearms; for example, gunpowder, dynamite, etc. (Fay).

Exposure.—(Geology.) The condition or fact of being exposed to view, either naturally or artificially. Hence, also, that part of a rock bed or formation which is so exposed; an outcrop (La Forge).

Extra heavy.—When applied to pipe, means pipe thicker than standard pipe; when applied to valves and fittings, indicates goods suitable for a working pressure of 250 pounds per square inch (National Tube Co.).

Extra strong.—The correct term or name for a certain class of pipe which is heavier than standard pipe and not as heavy as double extra strong pipe. Often less correctly called extra heavy pipe (National Tube Co.).

Extraction.—The process of separating, by solvents or by distillation, the desired part of a complex mixture from the undesirable residue.

Exude.—To discharge gradually through pores or small openings, as liquid, gum (oil or gas); to give off or out by slow percolation; as, the pines *exude* pitch (Standard). To ooze or flow slowly forth through pores, cracks, or gashes; as, gas and oils *exude* from the underlying formation.

Fahrenheit.—A thermometer scale with the freezing point of water at 32° and the boiling point at 212°. Degrees Fahrenheit = (Degrees Centigrade$\times\frac{9}{5}$) + 32 = (Degrees Réaumur$\times\frac{9}{4}$) + 32.

Fat.—(1) A white or yellowish substance forming the chief part of adipose tissue. It may be solid or liquid. It is insoluble in water. When treated with an alkali, the fatty acid unites with the alkaline base to form soap (Rickard).

(2) Containing an excess. A fat asphalt mixture is one in which the excess of asphalt cement is clearly apparent.

Fatty acids.—Acids of the series $C_nH_{2n}O_2$. They are called fatty acids because some of the higher members occur in fats. The lower members are liquids; the higher ones, starting with caproic acid, $C_{10}H_{20}O_2$, are solids at ordinary temperature. (Webster).

Fault.—(1) (Geology.)—A break in the continuity of a body of rock, attended by a movement on one side or the other of the break, so that what were once parts of one continuous rock stratum or vein are now separated. The amount of displacement of the parts may be a few inches or thousands of feet. **Closed fault:** A fault in which the two walls are in contact (Lindgren). **Dip:** A fault whose strike is approximately at right angles to the strike of the strata (Lindgren). **Dip slip:** A fault in which the net slip is practically in the line of the fault dip (Lindgren). **Distributive:** See Slip fault. **Flaw:** A rare type of fault (described by Luess) in which the strike is transverse to the strike of the rocks, the dip high and varying from one side to the other in the course of the fault, and the relative movement practically horizontal and parallel with the strike of the fault (Lindgren). **Gravity:** See Normal fault. **Hinge:** A faulting about an axis normal to the plane of faulting, which may produce a fault that on one side of the pivotal axis would be called normal and on the other side reverse; yet there may not be any differential movement in the center of the mass of two parts of the faulted body (Leith). **Horizontal:** A fault with no vertical displacement (Webster). **Longitudinal:** A fault whose strike is parallel with the general structure (Lindgren). **Normal:** A fault in which the hanging wall has been depressed relatively to the foot wall (Lindgren). **Oblique:** A fault whose strike is oblique to the strike of the strata (Lindgren). **Oblique slip:** A fault in which the net slip is between the direction of dip and the direction of strike (Lindgren) **Open:** A fault in which the two walls are separated (Lindgren). **Overlap:** A thrust fault in which the shifted strata double back over themselves (C. and M. M. P.). **Parallel displacement:** A fault in which all straight lines on opposite sides of a fault and outside of the dislocated zone, that were parallel before the displacement, are parallel afterward (Lindgren). **Pivotal:** See Hinge fault.

Reverse: A fault in which the hanging wall has been raised relatively to the foot wall (Lindgren). **Rotary**: A fault in which some straight lines on opposite sides of the fault and outside of the dislocated zone, parallel before the displacement, are no longer parallel, that is, where one side has suffered a rotation relative to the other (Lindgren). **Step**: A series of closely associated parallel faults (Webster). **Strike slip**: A fault in which the net slip is practically in the direction of the fault strike. J. Geike calls such faults "transcurrent faults." Jukes-Brown designates them "heaves" (Lindgren). **Strike**: A fault whose strike is parallel to the strike of the strata (Lindgren). **Thrust**: A reverse fault (Leith). **Transcurrent**: See Strike slip fault. **Translatory**: See Rotary fault. **Vertical**: A fault in which the dip is 90° (Lindgren).

Fault block.—A body of rock bounded by faults (Webster).

Fault breccia.—The breccia which is frequently found in a shear zone, more especially in the case of thrust faults (Lindgren).

Fault dip.—The inclination of the fault plane or shear zone, measured from a horizontal plane (Lindgren).

Fault escarpment; scarp.—An escarpment or cliff resulting from a fault or a dislocation of the adjacent rocks (Century).

Fault fissure.—The fissure produced by a fault, even though it is afterwards filled by a deposit of minerals (Century).

Fault line; trace.—The intersection of a fault surface or plane with the surface of the earth or with any artificial surface of reference (Lindgren). Compare trend. The line of intersection of a fault plane with the surface (Leith).

Fault plane.—A surface along which dislocation or faulting has taken place (Fay).

Fault strike.—The direction of the intersection of the fault surface, or the shear zone, with a horizontal surface (Lindgren).

Fault terrace.—A terrace formed by two parallel fault scarps on the same declivity, "thrown" in the same direction (Standard).

Fee.—Land operated for oil, gas, etc., under right of ownership as contrasted with land operated under lease.

Fells shale.—A Scottish oil-shale, said to be the richest in Scotland, which yields from 26 to 40 gallons of crude oil and from 20 to 35 pounds of ammonium sulphate per ton (Bacon).

Field work.—Work done, observations taken, or other operations, such as triangulation, leveling, making geological observations, etc., in the field or on the ground (Century).

Filter.—(1) Any porous article, as cloth, paper, sand or charcoal, through which water of other liquid is passed to separate from it matter held in suspension.
(2) To pass through; to percolate (Webster).

Filtered stock.—Lubricating stock that has been filtered through fuller's earth, or any other filtering medium (A. D. Smith).

Filtrate.—The liquid which has passed through a filter (Century).

Filtration.—The act or process of filtering: the process of mechanically removing the undissolved particles in a liquid by passing the liquid through filtering paper, charcoal, sand, etc. (Century).

Fines.—Rock or mineral in too fine or pulverulent a condition to be treated in the same way as ordinary coarse material.

Finishing.—Preparing (oils) for a specified use.

Fire-damp.—A combustible gas or "damp" formed by the decomposition of coal or other carbonaceous matter, and consisting chiefly of methane CH_4; also, the explosive mixture formed by this gas (5.5 to 13 per cent) and air (Webster). The gas is contained in the coal and given off in large quantities, and explodes upon ignition when mixed with atmospheric air (Fay).

Fire test.—The lowest temperature at which, under definite specified conditions, a petroleum product vaporizes sufficiently rapidly to form, above its surface, an air vapor mixture which burns continuously for at least five seconds when ignited by a small flame (Delbridge).

Fishing.—Pulling up or out from some deep place, as if by fishing. Said of recovering lost or broken well-boring tools.

Fishing jars.—Jars used with fishing tools to recover lost tools or casing from a hole. They have a longer stroke than those used in drilling (Sands).

Fittings.—A term used to denote all those pieces which may be attached to pipes in order to connect or provide outlets, etc., except couplings and valves (National Tube Co.).

Fixation.—The act or process by which a fluid or a gas becomes or is rendered firm or stable in consistency, and evaporation or volatilization prevented. Specifically, in chemistry, that process by which a gaseous body becomes fixed or solid on uniting with a solid body; as, fixation of oxygen, fixation of nitrogen (Century).

Fixed carbon.—The organic matter of the residual coke obtained upon burning hydrocarbon products in a covered vessel in the absence of free oxygen (Bacon). That part of the carbon which remains behind when coal is heated in a closed vessel until the volatile matter is driven off (Steel). It is the non-volatile matter minus ash (Webster).

Flange.—A projecting rim, edge, lip or rib (National Tube Co.). A plate to close a pipe opening or other orifice (Standard).

Flanged joint.—A joint in pipes made by flanges bolted together (National Tube Co.).

Flanged pipe.—Pipe provided with flanges so that the ends can be held together by means of bolts (National Tube Co.).

Flange union.—A fitting consisting of a pair of flanges and bolts to connect them, for use on threaded pipe. Compare Union (National Tube Co.).

Flash test or point.—The lowest temperature at which, under definite specified conditions, a petroleum product vaporizes rapidly enough to form above its surface an air vapor mixture which gives a flash or slight explosion when ignited by a small flame (Delbridge).

Flint.—A dense, fine-grained form of silica which is very tough and breaks with a conchoidal fracture and cutting edges. See also Chert (U. S. Geol. Survey).

Float.—(1) The floating part of an apparatus for indicating the height of water in a steam boiler or other vessel (Fay).

(2) Fragments of a bed, exposed on the surface but not in place.

Flock, floc.—Any small tufted or flake-like mass of matter floating in a solution, especially if produced by precipitation (Standard).

Flocculent.—Resembling wool, therefore wooly, coalescing, and adhering in flocks. A cloud-like mass of precipitate in a solution (Rickard).

Floc test.—A qualitative test applied to illuminating oils for the detection of substances rendered insoluble by heat (Delbridge).

Floridin.—Fuller's earth from Quincy and Jamieson, Florida, used in decolorizing petroleum products (Bacon).

Flotation oil.—An oil used for flotation purposes; usually a pine oil or turpentine or a coal-tar derivative, although petroleum products have been successfully used for flotation purposes.

Flotation process.—A concentration process that takes advantage of the principles of surface tension and colloid chemistry, with whatever allied principles may be involved, to separate mineral from gangue by means of floating it upon the surface of water or other solutions, while the gangue is induced to sink through the surface and settle separately (Megraw). The process or processes by which the valuable minerals in a mass of finely ground ore can be caused to float on a liquid into which the finely ground ore is fed. Classified as film flotation and froth flotation (Ralston, U. S. Bur. Mines).

Flowing well.—An oil well in which pumping is not necessary to bring the oil to the surface (Redwood).

Flow tank.—The tank to which the oil is piped from the well, to settle.

Flow test.—See Pour test.

Flue.—A passage for air, gas, or smoke (Raymond). A British term used in the same sense as the term tube is used in America (National Tube Co.).

Fluid.—Having particles which easily move and change their relative position without separation of the mass, and which easily yield to pressure; capable of flowing; liquid or gaseous (Webster).

Fluidimeter.—An instrument devised by H. Joshua Phillips for determining the fluidity of oils at various temperatures (Mitzakis).

Fluid inclusion.—A liquid inclosed in a cavity, usually very minute, in a mineral (Century).

Fluorescence.—The emission of light from within a substance while it is being exposed to direct radiation, or in certain cases, to an electrical discharge in a vacuum tube (Dana).

Flush.—To clean out (a line of pipes) by letting in a sudden rush of water.

Flush bushing.—See under Bushing.

Flush production.—The yield of an oil well during the early period of production and before the output has settled down to what may be regarded as usual for the field or district in which it is drilled (Redwood).

Fluted swedge.—A tool used for straightening out crooked or dented casing in the hole (Sands).

Flux.—A heavy reduced residuum from an asphalt base crude; a maltha (A. D. Smith). Bitumens, generally liquid, used in combination with harder bitumens for the purpose of softening the latter (Bacon).

Foaming.—A method of extinguishing oil fires by spraying with a foaming liquid.

Foamite.—The trade name for a preparation used in smothering oil fires. A proprietary concentrated extract of licorice root. When mixed with bicarbonate of soda solution in proper proportion, it yields a solution containing an equivalent acid radical, and produces a mass of foam impregnated with carbonic acid gas (A. D. Smith).

Fold.—A strong flexure of a stratum with steeply inclined sides; loosely and more commonly, any flexure of a stratum (Standard).

"Foots" oil.—An oil containing only low melting point wax of little market value. and yet too high a cold test, and too low viscosity for a lubricating product (A. D. Smith).

Forced production.—The working of a mine or well so as to make it produce a greater output than can be maintained.

Force pump.—A pump that forces water above its valves (C. and M. M. P.).

Forechamber.—An auxiliary combination for gas-fired boilers, that provides an incandescent surface for lighting gas instantly when turned on after being shut off for any reason. Also called Dutch oven and dog house (Willcox).

Fork.—An appliance used in free-fall systems of drilling, which serves to hold up the string of tools during connection and disconnection of the rods (Mitzakis).

Formation.—The ordinary unit of geologic mapping, consisting of a large and persistent stratum of some one kind of rock (U. S. Geol. Survey). It is also loosely employed for any local and more or less related group of rocks.

Formation map.—Map showing rock formation by use of color or by various line or symbol patterns, dips and strikes usually shown by letter T. This type of map is generally used where strata have steep dips, gently dipping beds being mapped by contours.

Formolite.—For the determination of the unsaturated cyclic hydrocarbons in a mineral oil, the oil is treated with formaldehyde in the presence of concentrated sulphuric acid, whereby a solid yellow product is separated, for which the name " formolite " has been proposed (Bacon).

Fossil.—(1) Originally, any rock, mineral or other object dug out of the earth.

(2) Now, any remains, impressions, or traces of an animal or plant of past geological ages, which have been preserved in a stratified deposit or in a cave (Webster).

Fractional distillation.—An operation for separating a mixture of two or more liquids which have different boiling points (Century). Used extensively in petroleum distillation.

Fractionate.—To separate a mixture (as a liquid by distillation) into fractions having more or less fixed properties but which are not necessarily definite compounds (Standard).

Fractionation.—Separation by successive operations, each removing from a liquid some proportion of one of the substances. The operation may be one of precipitation, or of crystallization, or of distillation (Century).

Frasch process.—A desulphurizing process which consists of distilling oil with copper oxide, followed by refining with sulphuric acid.

Free carbon.—In tars, organic matter which is insoluble in carbon disulphide (Bacon).

Freeze.—To set in a drill hole so that it cannot be pulled out (said of a pipe).

Freezing point.—The temperature at which oil ceases to flow when the bottle is inverted.

Friable.—Easily crumbled or pulverized; easily reduced to powder, as pumice.

Fuel gas.—Gas used for heating, as distinguished from illuminating gas (Standard).

Fuel oil.—(1) Any product of petroleum used for the production of power or heat.

(2) From another standpoint, fuel oils are the distillates heavier than illuminating oils and lighter than lubricating oils ranging from 25° to 30° Bé. (Bacon). Heavy crude and residual oils when used as fuels. This grade is produced in enormous quantities by continuous skimming plants in the Southwest, and by topping plants on the Pacific Coast. It varies from 26° to 14° Bé. gravity, with corresponding fluctuations in its other physical constants. These depend on the nature of the crude, the extent of gas-oil or stove distillate stripped, the amount of bottom steam used, etc. Its color ranges from dark green to black, its cold test from 80°

to 10° F. It is commonly marketed in the Mid-Continent field on guaranteed gravity alone, such as 26° to 28°, 24° to 26°, 22° to 24° Bé. gravity fuel oil.

Fuel ratio.—The amount of heating capacity in a fuel as compared with another fuel taken as a standard (Century).

Fuller's earth.—A fine earth resembling clay. It is much the same chemically as clay, but has a decidedly higher percentage of water (Kemp). It possesses the property of decolorizing oils and fats by retaining the coloring matter.

Fuming sulphuric acid.—An acid made by dissolving sulphur trioxide in concentrated sulphuric acid; Nordhausen acid (Webster).

Fuse.—To unite or blend as if melted together (Webster).

Gabian.—A variety of petroleum obtained at Gabian, Department of Hérault, France (Standard).

Gage; gauge.—To measure or ascertain the amount or contents of, or the capacity of, as of a pipe, barrel or keg. A standard measure of dimensions, distance, or capacity (Webster).

Gager.—One whose business it is to systematically determine the amount of oil in a producer's storage.

Gaging nipple.—A small projecting hatch, usually cylindrical in form, about 3 to 4 inches in diameter, located in the roof of a tank close to the manplate; a small aperture, preferably with self-closing cover which permits the gaging of the tank contents without the necessity of removing the larger manplate (A. D. Smith).

Gallon.—The standard gallon of the United States contains 231 cubic inches, or 8.3389 pounds avoirdupois of distilled water at its maximum density and with a barometer of 30 inches. The English Imperial gallon contains almost exactly 1.2(U. S. gallons (Webster).

Gas.—An aeriform fluid, having neither independent shape nor volume, but tending to expand indefinitely (Webster). Gas is considered as a mineral, and while "in situ" is a part of the land (Westmoreland, etc. Gas Co. *vs.* DeWitt, 130 Pennsylvania Statutes).

Gas black.—A superior kind of lampblack, collected by introducing a cold iron surface into a luminous gas flame (Webster).

Gas carbon.—A compact variety of carbon obtained as an incrustation on the interior of gas retorts, and used for the manufacture of carbon rods or pencils for the electric arc, and for the plates of voltaic batteries (Webster).

Gas coal.—Any coal that yields a large quantity of illuminating gas in distillation (Gresley). It should be low in sulphur and other impurities.

Gas coke.—The coke formed in gas retorts, as distinguished from that made in coke ovens (Webster).

Gas detector.—A device to show the presence of fire-damp, etc., in a mine (Standard).

Gas engine.—A kind of internal-combustion engine using fixed gas; also, broadly, any internal-combustion engine (Webster).

Gaseous.—(1) In the form, or in the nature, of gas; pertaining to gases.
(2) Lacking substance or solidity (Webster).

Gas field.—A tract or district yielding natural gas (Webster).

Gas firing.—The combustion of coal effected by burning in such a way as to produce a combustible gas, which is then burned secondarily in the furnace (Ingalls).

Gas furnace.—A furnace using gas for fuel, or one for making gas (Webster).

Gas gage.—An instrument for ascertaining the pressure of gas, generally consisting of a bent graduated tube containing water or mercury, open at one end, with the other end screwed into the vessel containing the gas (Century).

Gas generator.—(1) An apparatus for generating gas, such as a retort in which hydrocarbons are evolved by heat.

(2) A carburetor.

(3) A machine for the production of carbonic acid gas, for aerating water (Webster).

Gas-house coal tar.—Coal tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal (Bacon).

Gasket.—A thin sheet of composition or metal used in making a joint water, gas, or steam-tight (National Tube Co.).

Gas-oil.—(Light.)—A product, intermediate between "heavy end" and paraffin distillate. This is distinguished from heavy gas-oil obtained in the subsequent reduction of paraffin distillate. As cut from crude, gas-oil usually runs 33° to 37° Bé. gravity, 175° F. flash, or better, is a straw color, and varies in cold test from 30° to 10° F., depending ont he nature of the crude, and the cuts employed. It finds direct sale as an absorbent or scrubbing oil, and when mixed with heavier gas-oils, forms the 32° to 36° Bé. oil of the trade. It is also sold for special fuel and may be further refined into grease stock or light non-viscous lubricants (A. D. Smith).

Gasoline.—The commercial name applied broadly to the lighter products derived from the distillation of petroleum. It is volatile, inflammable, and used chiefly as a fuel in internal-combustion engines of the automobile type; also as a solvent for fats and oils for the generation of gas, and as a fuel in vapor stoves. The specifications for motor gasoline, under which a very large percentage of the product is sold, vary. When obtained by direct distillation from crude, it runs about 21 to 25 in color; 95° to 120° F. initial boiling point; 350° to 400° F. end point; and 64° to 66° Bé. gravity. This grade is made from comparatively few crudes and is used principally for blending. Specific gravity is no longer included in gasoline specifications.

Gas producer.—A furnace in which coal is burned for the manufacture of producer gas. There are two types, namely: (1) the step-grate, natural-draught generator, which is but a development of the ordinary firebox. (2) the shaft furnace, with or without a grate and worked by a natural draft or forced draft. The latter type is identical in many respects with a blast-smelting furnace. The principal producers are: Boettius, Dawson, Dowson, Duff, Hegeler, Mond, Siemens, Smythe, Swindell, Talbott, Taylor, Wellman, and Wilson (Ingalls).

Gas rights.—See oil rights.

Gas sand.—A sandstone containing natural gas (Webster).

Gas separator.—See Gas trap.

Gasser.—A well that yields gas, especially an oil well producing much gas (Webster).

Gas spurts.—Little heaps observed on the surface of certain geological strata containing organic matter; so called because believed to be due to the escape of gas (Webster).

Gassy.—Characteristic of or impregnated with gas, especially coal gas (Standard). Applied to any mine which generates methane, or any other gas.

Gas tank.—See Gas trap.

Gas tar.—Coal tar obtained as a by-product in the manufacture of illuminating gas (Webster).

Gas trap.—One of many devices for separating and saving the gas from the flow and lead lines of producing oil wells. The mixture of oil and gas is allowed to flow through a chamber large enough to reduce the velocity of the mixture to the point at which the oil and gas tend to separate. The gas seeking the top of the chamber is drawn off from the oil, while the oil is discharged at the bottom (Tech. Paper No. 209, Bur. Mines). Also called Gas separator, Gas tank.

Gas water.—Water through which coal gas has been passed, and which has absorbed the impurities of the gas (Century).

Gas well.—(1) A deep boring from which natural gas is discharged (Raymond).

(2) As used in oil and gas leases, a well having such a pressure and volume of gas, taking into account its proximity to market, that it can be utilized commercially (Pritchard *vs.* Freeland Oil Co., 84 S. E. Rep., p. 946).

Gas works.—A manufactory of gas, with all of its machinery and appurtenances; a gas plant (Webster).

Gas zone.—A formation which contains capillary or supercapillary voids, or both, that are full of natural gas under considerably more than the atmospheric pressure.

Gate valve.—A sluice valve; one having two inclined seats between which the valve wedges down in closing, the passages through the valve being in an uninterrupted line from one end to the other, while the valve, when opened, is drawn up into a dome or recess, thus leaving a straight passage the full diameter of the pipe (National Tube Co.).

Gathering lines.—Pipes connecting production tanks at oil wells with trunk pipe-lines.

Gauge.—See Gage.

Gauger.—See Gager.

Gauging nipple.—See Gaging nipple.

Geanticline.—An anticline so extremely long and broad that it constitutes more than a local feature (Clapp).

Gelatin dynamite.—An explosive, the composition of which varies between wide limits, depending upon its use. A typical composition is 62.5 per cent nitroglycerin; 2.5 collodion cotton; 25.5 sodium nitrate; 8.7 meal; 0.8 soda (Brunswig). It is a plastic, waterproof high explosive of great density, used principally for close work and where it is exposed to water (Du Pont).

Gelignite.—The term by which gelatin dynamite is known abroad (Du Pont).

Generator.—A vessel, chamber or machine in which the generation of a gas is effected; as by chemical action (Standard).

Generator gas.—Producer gas (Webster).

Genetic.—Of or pertaining to genesis in any way; as regards origin or mode of production.

Geological horizon.—Rocks of one geological age (Weed).

Geologic high.—Sometimes used in oil-fields to indicate a later geological formation, regardless of elevation; opposed to geologic low, which refers to earlier formation. Compare Topographic high (Fay).

Geology.—The science which treats of the history of the earth and its life, especially as recorded in the rocks. Three principal branches or phases are usually distinguished: (1) **Structural,** or **geotectonic** geology, treating of the form, arrangement, and internal structure of the rocks. (2) **Dynamic** geology, dealing with the causes and processes of geological change. (3) **Historical** geology, which, aided by other branches, aims to give a chronological account of the events in the earth's history (Webster). Other subdivisions are: **Economic** geology, that branch of

geology which deals with the applications of the science in industrial relations and operations; **Stratigraphic** geology, a study of the succession of the beds of rock laid down during the progress of geologic ages (Shamel); and **Petroleum** or **Oil** geology, which treats of the geologic factors involved in the origin, accumulation, and production of petroleum.

Geosyncline.—A great downward flexure of the earth's crust; opposed to geanticline (Fay).

Gilsonite.—An asphaltite; a hard, black asphalt of homogeneous texture, which softens and flows at a high temperature. It is exceedingly brittle and breaks with a lustrous conchoidal fracture which soon becomes dead black on exposure to the weather. Gilsonite has a wide variety of uses in the industries. Properly fluxed with a heavy asphaltic oil, it forms an asphalt of peculiar rubbery texture, only very slightly susceptible to temperature changes. It is also valuable as a base for marine paints and protective coatings for steel work, for use in the manufacture of automobile tires and other rubber products, for insulation and for roofing materials (R. G. Smith).

Girth sheets.—The steel plates forming the sides of an oil still (A. D. Smith).

Gland.—The outer portion of a stuffing box, having a tubular projection embracing the rod, extending into the bore of the box, and bearing against the packing (Standard).

Globe valve.—A valve with approximately a spherical chamber. A valve in which a ball is pressed against a seat to close it (Standard).

Globule.—A small globe or spherical particle. Often applied to particles of liquids found in rock cavities, or suspended in other liquids (Webster).

Glossary.—A collection of notes or explanations of words and passages of a work or author; a partial dictionary of a work, an author, a dialect, art, or science, explaining archaic, technical, or other uncommon words (Webster).

Go-devil.—(1) A scraper with self-adjusting spring blades, inserted in a pipe-line and carried forward by the fluid pressure, clearing away accumulations from the walls of the pipe (National Tube Co.).

(2) This term is also applied to a device for exploding the nitroglycerin used to shoot an oil well (Redwood).

Goudron.—A Russian petroleum product possessing a specific gravity of at least 0.935 and a flash point of at least 270° C., often the equivalent of tar.

Grahamite.—A comparatively pure, brittle, black bitumen which does not melt at a high temperature, but merely intumesces. It is rarely of compact structure, often containing a large proportion of inorganic impurities, and when it is fractured the break is irregular or hackly and the broken surface dull (R. G. Smith). When mixed with heavy asphaltic fluxes, it is very rubbery and elastic and non-susceptible to heat changes. It is used as a substitute for rubber, as a filler between stone and brick blocks, and in the manufacture of flooring, varnishes, and paints.

Gram.—Weight of one cubic centimeter of water = 15,432 grains.

Gravimetric analysis.—The quantitative determination of the constituents of a compound by weight; contrasted with volumetric analysis (Standard).

Gravitation.—The force by which all bodies attract each other, specifically applied to the force by which the earth attracts bodies (Webster).

Gray shale.—A shale, which was worked at Addiewell, Scotland, lying above the Houston coal, which consists of several thin coal seams (Bacon).

Gray's tester.—An instrument used for determining the flashing point of heavy oils (Mitzakis).

Grease.—Properly speaking, this term should only be applied to fatty or oily matter of animal origin; but mixtures of mineral oil with lime-and-soda soaps constitute well-known lubricating greases (Bacon).

Grease box, or cup.—A box or cup containing fat or grease for lubricating a bearing.

Grease plant.—An auxiliary department of certain refineries, in which lime-and-soda soaps of various fatty products, such as inedible lard and tallow oils, horse oil, etc., are compounded with non-viscous paraffin oils or other petroleum products into semi-fluid or pastry lubricants technically called " greases " (A. D. Smith).

Green oil.—In the Scottish shale-oil industry, the once-run crude oil after chemical treatment. It is distilled in the first-stage oil stills and is fractioned into naphtha, light oil, heavy oil, and heavy oil and wax (Bacon).

Green tar.—Barbados petroleum. (Bacon).

Grief stem.—A heavy fluted or square steel pipe which is screwed on at the top of the drill pipe and is engaged by the bushing or grips in the turn table (Sands).

Ground water.—The water which permeates, in an unbroken sheet, the rock masses of the earth, filling their pores and fissures (Fay).

Ground-water level.—The level below which the rock and subsoil, down to unknown depths, are full of water (Chamberlain).

Grout.—A thin cement mixture forced into the crevices of a stratum to prevent ground water from seeping or flowing into an excavation. Frequently employed in shaft sinking and bore-hole drilling.

Growler board.—The foundation for the jack and jack boards, in laying pipe-lines (Towl).

Gumbo.—Any relatively sticky formation, such as clay, encountered in drilling.

Gum dynamite.—Explosive gelatin (Standard).

Gum resin.—The semi-solid to solid and usually light-colored emulsion or mixture of true resins with various gums (carbohydrates), constituting the sap of certain plants and trees, partly soluble in water (Bacon).

Gurley compass.—A combined compass and clinometer. It has a square metal base with beveled edges which are graduated on two sides in inches and on two sides in degrees of arc. It has a pair of folding open sights, a swinging clinometer and retangular spirit levels.

Gusher.—An oil well with a large natural flow (Webster).

Guy.—A guide; a rope, chain, or rod attached to anything to steady it; a rope which holds in place the end of a boom, or spar; a rod or rope attached to the top of a derrick and extending obliquely to the ground where it is fastened (Webster).

Guy anchor.—The support to which derrick guys are attached (Bowles).

Guy rings.—Rings on the head block of a derrick mast, to which the guy ropes are attached (Standard).

Gypsum.—Hydrous calcium sulphate, $CaSO_4+2H_2O$. It contains 32.5 per cent lime, 46.6 per cent sulphur trioxide and 20.9 per cent water (Fay).

Half-turn socket.—In oil-well drilling, a fishing tool having jaws bent around in an incomplete circle, to embrace lost tools lying against the side of the well (National Tube Co.).

Hand-dug wells.—The earliest known method of extracting petroleum was by means of pits dug by hand labor. The usual method was to dig a few feet and then allow the oil to collect at the bottom, whence it was subsequently collected by means of a suitable vessel. The deepest of these wells rarely exceeded 50 feet (Mitzakis). In Rumania, many deep wells have been dug by hand, occasionally below 1000 feet.

Hand level.—An instrument used in field mapping to determine differences in elevation. It can only be used in the crudest type of geological mapping, such as making short branch traverses or "side shots."

Hard pitch.—Pitch showing a penetration of not more than 10 (Bacon).

Head.—Pressure due to height.

Headache post.—An upright timber in a derrick which may serve to support the forward portion of the walking beam.

Header.—A large pipe into which sets of boilers are connected by suitable nozzles or tees, or similar large pipes from which a number of smaller ones lead to consuming points. Largely used for tubes of water-tube boilers (National Tube Co.).

Heads.—The circular end plates of an oil still (A. D. Smith).

Headgear.—That part of deep-boring apparatus which remains at the surface (Raymond).

Heat.—A physical agent or form of energy generated by the transformation of some other form of energy, as by combustion, chemical action, or the stoppage of mass-motion by friction, possessing the power of expanding, melting, vaporizing, and decomposing bodies, of raising their temperature, and of passing through space with the velocity of light (Standard).

Heat energy.—That form of energy which manifests itself through thermal effects (Webster).

Heat exchange.—A system of heating oil, water or gas by absorbing the heat from some medium which must be cooled; as hot air or vapor.

Heat of combustion.—The heat evolved when a substance is completely burned in oxygen (Fay).

Heat test.—A test applied to lubricating and transformer oils to determine their stability toward heat and also to detect incomplete or improper refining for specific purposes. (Delbridge).

Heat unit.—A unit of quantity of heat; the heat required to raise the unit mass of water through 1° of temperature, within specified temperature range. Compare Calorie; also British thermal unit.

Heavy carbureted hydrogen.—Ethylene; often called olefiant gas.

Height of instrument.—(H. I.)—The elevation above mean sea level of the line of sight in a surveying instrument.

Height of tank.—The height of the shell from top of bottom sheet to top of upper reinforcing angle; the maximum available height for liquid (A. D. Smith).

Heterogeneous.—Differing in kind; having unlike qualities; possessed of different characteristics; opposed to homogeneous (Webster).

High dip.—A dip of over 5 per cent which may be measured or recorded in degrees of inclination.

Hog still.—A refinery colloquialism for a simple form of tower still in which the very light products only, such as benzine (gasoline) are separated by the use of steam (A. D. Smith).

Hoist.—See Draw works.

Hole.—A bore-hole (Steel).

Hollow reamer.—A tool for straightening a crooked bore-hole (Gresley).

Homocline.—A monocline. A succession of beds dipping in one direction.

Homogeneous.—Of the same kind or nature; consisting of similar parts, or of elements of a like nature; opposed to heterogeneous (Webster).

Homologous.—Having a similar structure, proportion, value, or position; proportional to each other identical in nature, relation, or the like (Webster).

Homologous series.—A series of organic compounds, the members of which differ from each other by a multiple of CH_2 (Webster).

Horizon.—The strata all over the earth which were formed at the same time are said to belong to the same geological horizon.

Horizontal segment.—A segment of a circle lying in a horizontal plane; particularly applied to the half segment formed by a measuring tape drawn over the vertical lap joint of the side sheets of a tank (A. D. Smith).

Horn socket.—In well boring, an implement to recover lost tools, especially broken drill poles, etc. It consists of a conical socket, the larger end downward, which slides over the broken part, a spring latch gripping it when entered. Frequently a flaring mouthpiece is riveted to the horn socket, making it a bell-mouth socket (National Tube Co.).

Horsepower.—A unit of power numerically equal to a rate of 33,000 foot-pounds of work per minute (550 foot-pounds per second), used in stating the power of a steam engine or other prime mover (Webster).

Housing.—The casing for a machine or part thereof (Fay). It is also a device for shutting off a leak in a pipe or fitting.

Hydrate.—A compound formed by the union of water with some other substance and represented as actually containing water; a hydroxide, as calcium hydrate (Fay).

Hydrated.—Containing water in chemical combination, and hence in a definite proportion in each case; as gypsum, which contains water of crystallization; calcium hydrate, lime which has absorbed water (Roy. Com.).

Hydraulic.—Of or pertaining to fluids in motion; conveying, or acting by water, as hydraulic mining (Fay).

Hydraulic circulating system.—A method of drilling by which mud-laden fluid is circulated during cable-tool drilling (Sands).

Hydraulic jack.—A jack for lifting, pressing, etc., in which pressure on the moving part is transmitted by a liquid, as water or oil.

Hydride.—Combination of hydrogen with a radical group or an element.

Hydrocarbon.—A compound containing only hydrogen and carbon. The simplest hydrocarbons are gases at ordinary temperatures; with increase in molecular weight they change to the liquid, and finally to the solid state (Webster).

Hydrocarbon black.—A name for lampblack.

Hydrogen.—A gaseous element, colorless, odorless, tasteless, inflammable, and lighter than any other isolated element. Symbol, H; atomic weight, 1.01; specific gravity 0.07.

Hydrolysis.—A chemical decomposition by which a compound is broken up and resolved into other compounds by taking up the elements of water (Century).

Hydrometer.—A graduated instrument for determining the gravity of liquids.

Hydrophilic.—(Said of colloids.)—Possessing a property whereby they take up water in conjunction with the molecules of the colloid in a manner analogous to a closed hydrated molecule. Hydrophilic colloids are valuable dispersing mediums for making emulsions (Rickard).

Hydrostatic balance.—A balance for weighing substances in water to ascertain their specific gravity (Webster).

Hydrostatic pressure.—The pressure exerted by a liquid, as water, at rest (Standard).

Hydrostatics.—That branch of physics which relates to the pressure and equilibrium of liquids. The principles of statics applied to water and other other liquids (Webster).

Hydrous.—Containing water chemically combined, as in hydrates or hydroxides (Webster).

Hydroxide.—A compound of an element with the radical or ion, OH, as sodium hydroxide, NaOH.

Hygrometer.—An instrument or apparatus for measuring the degree of moisture of the atmosphere (Webster).

Hygroscopic.—Having the property of readily absorbing moisture from the atmosphere (Power).

Ichthyol.—A water-soluble oil which is obtained by the distillation of bituminous shales and subsequent sulphonation and neutralization with ammonia and salt.

Illuminating oils.—Oils used for illuminating purposes. They are petroleum products heavier than gasoline, ranging from 90° to 250° flash point.

Immiscible.—Not capable of mixing, as oil and water (Standard).

Impalpable.—Extremely fine, so that no grit can be perceived by touch (Webster).

Impervious.—Impassable; applied to strata such as clays, shales, etc., which will not permit of the penetration of water, petroleum, or natural gas (Roy. Com).

Impregnated.—Said of a rock or other body, the pores of which are more or less filled with extraneous material, such as oil or tar.

Incrustation.—A deposit left on the surface by the evaporation of a liquid or by deposit from a liquid; as, for example, the crust left in a boiler by the evaporation of water.

Index of refraction.—A number which expresses the ratio of the sine of the angle of incidence to the sine of the angle of refraction (Webster).

Indicated horsepower.—The horsepower actually calculated from the indicator card (Goldingham).

Indications.—Substances found on the earth's surface, by which the occurrence of petroleum may be inferred. They include asphaltum, natural gas, films of oil, etc.

Inflammable.—Easily set on fire; as, an inflammable gas (Standard).

Initial boiling point.—In a standard laboratory distillation, the temperature on the distillation thermometer at which the first drop of distillate falls from the condenser (Delbridge).

Initial daily production.—Number of barrels of oil yielded by a new well during the first twenty-four hours after having been put in proper condition for pumping or flowing.

Injector.—Mechanism used for spraying fuel oil into the combustion chamber, feeding water into steam boilers, or as a pump for exhausting gases from shale furnaces.

Inspissated.—Thickened, as by evaporation and oxidation; as the pitch or gum resulting from petroleum after long exposure.

Internal combustion.—Pertaining to any engine in which the heat or pressure energy necessary to produce motion is developed in the engine cylinder, as by the explosion of gas (Webster).

Internal-combustion engine.—A self-contained unit arranged to receive, within its cylinder, vaporizer, or combustion chamber, liquid heavy crude or fuel oil, petroleum distillates, or other similar fuels. Such products are first vaporized and intimately mingled in the combustion space with air compressed by inward movement of the piston of the engine. Ignition of the explosive mixture thus formed takes place with the consequent evolution of the heat energy contained in the fuel, which is thus converted into work (Goldingham).

Interval.—The perpendicular distance between two parallel lines, as for example, contour lines.

Intervisible.—Term in surveying, said of stations when they are mutually visible one from the other (Century).

Inversion.—The folding back of strata upon themselves, as by the overturning of a fold, in such a manner that the order of succession appears to be reversed (Webster).

Iodine value.—The percentage proportion of iodine absorbed by an oil or the number of grams of iodine absorbed by 100 grams of the oil. Used in the determination of unsaturates.

Iridescence.—The exhibition of prismatic colors in the interior or on the surface of a mineral (Dana).

Isoclinal, isoclinic.—(Geology.)—Dipping in the same direction; hence, an isocline (Standard).

Isoclinal fold.—(Geology.)—A stratigraphic fold whose sides have parallel dips; it may be an anticline or a syncline, and may be either (1) vertical, (2) overturned, that is, forced over into an oblique position, or (3) recumbent, that is, pushed over into nearly or quite a horizontal position (Fay).

Isocline.—(Geology.)—A series of isoclinal strata. An anticline or syncline so closely folded that the rock beds of the two sides or limbs have the same dip (Webster).

Isogenic lines.—Imaginary lines joining places on the earth's surface at which the variation of the magnetic needle from the meridian or true north is the same (Webster).

Isomeric.—Composed of the same elements united in the same proportion by weight, but differing in one or more properties owing to the difference in structure (Webster).

Isothermal line.—The line indicating the relation between the pressure and volume of a gas due to expansion or compression at a constant temperature (Goldingham).

Jack.—Mechanism installed at the mouth of an oil well for transmitting mechanical power from a central pumping station.

Jack boards.—Braces used to support pipe jacks (Towl).

Jack and circle.—The apparatus, consisting of a powerful jack and a steel-toothed circle on which the jack moves, used to tighten the joints in a string of tools.

Jar.—To drill by impact, as a rock; to use a drill jar upon (Standard). See Jars.

Jars.—In well-drilling, a connection between the sinker bar and the poles or cables made in the form of two links that slide on each other from 6 to 36 inches. The jars permit the tools to fall on the down stroke, but, on the up stroke, jar them, or give them a sharp jerk, tending to loosen them from any crevices or cavings that may hold them; a drill jar (National Tube Co.).

Jar socket.—A fishing tool.

Jet-black.—A name for lampblack.

Jet pump.—A pump which moves fluid by bringing it in contact with a rapidly moving stream of a fluid of the same or different kind, the motion being imparted through friction. Injectors and aspirators are pumps of this type (Meinzer).

Jig.—In well-boring, to drill with a spring pole (Century).

Joint.—In drilling, that part of a drilling or fishing tool by which connection is made with another member of the string. A complete joint consists of a threaded truncated cone, the pin and a corresponding coupling (the box), also a single piece of pipe or tubing usually about 20 feet in length (Sands).

Jolly balance.—A very delicate spring balance used especially for the determination of densities by the method of weighing in water and air (Webster).

Joule.—A unit of work or energy which is equivalent to 10^{7-7} ergs, and is practically equivalent to the energy expended in one second by an electric current of one ampere in a resistance of one ohm. Approximately equal to 0.738 foot-pound (Webster). The gram-degree centigrade thermal unit; the small calorie (Standard).

Joule's law.—The law that there is no change of temperature when a gas expands without doing external work and without receiving or rejecting heat (Webster).

Jumping a claim.—Taking possession of a mine or claim by stealth, fraud, or force (Fay).

Kelp oil.—Oil obtained by the distillation of dried kelp. It is rich in nitrogen.

Kerogen.—A term applied to the bituminous material in Scottish oil-shale (Bacon).

Kerosene.—A mixture of hydrocarbons, freed on the one hand from gasoline or naphtha and on the other hand from the heavy hydrocarbons that belong to gas oil and lubricating oil (Bacon). It is usually the fraction or cut of petroleum which distills between 150° and 300° C., and has been purified by treatment with sulphuric acid and alkali and occasionally washed with fuller's earth. See Illuminating oils.

Kerosene distillate, kerosene stock.—This product follows the light end or engine distillate, and varies in color, reaction to "doctor," burning quality, flash, etc., according to the nature of the crude. For direct sale or finishing by simple treatment, it usually runs 41° to 46° Bé. gravity, 150° to 175° F. burning point, but where cut for sweetening, rerunning, acid treatment, etc., its stands 40° to 44° Bé. gravity, and varies widely in flash and burning test (A. D. Smith).

Kerosene shale.—Speaking broadly, this term may be applied to any bituminous or oil-shale from which illuminating oil has been or may be obtained. The term is specifically applied, however, to the oil-shale found in New South Wales (Bacon).

Kewanee union.—A patented pipe union having one pipe end of brass and the other of malleable iron, with a ring or nut of malleable iron, in which the arrangement and finish of the several parts is such as to provide a non-corrosive connection between the ring and brass pipe end (National Tube Co.).

Key.—A kind of wrench used for screwing and unscrewing drill rods. Also used to support the rods by resting on top of the casing and allowing the rods to hang by the enlarged joint coming in contact with the key (Gresley).

Key bed.—See Key rock.

Key horizon.—See Key rock.

Key rock.—A stratum so persistent and identifiable over large areas as to be valuable in deciphering structure, such as Chattanooga shale, Pittsburgh coal, etc.

Key-sealing.—In drilling, vertical channeling of the walls of a hole (Sands).

Kilogram.—A unit of weight in the metric system, and equal to 1000 grams or 2.2046 pounds avoirdupois.

Kilometer.—A length of 1000 meters, equal to 3280.8 feet or 0.621 of a mile; the chief unit for long distances in the metric system (Standard).

Kilowatt.—A unit of power equal to 1000 watts (Webster).

Kilowatt hour.—A unit of work or energy equal to that done by one kilowatt acting for one hour; approximately 1.34 horse-power hours (Webster).

Kimmeridge shale.—(**Kim coal.**)—Extensive deposits of bluish-gray slaty clay, containing more or less volatile matter, and interstratified with thin beds of highly bituminous shale, occurring in Dorsetshire. This clay, which is a member of the Upper Oölite, attains in places a thickness of as much as 600 feet. Locally called Kim coal (Bacon).

Knock-off joint.—In well-drilling, a joint used in the rods of deep-well pumps. The jointed ends of the rods are enlarged to a square section and notched to fit against one another, and are confined by a clasp or bridle embracing them. The joint is tapered lengthwise and the hole in the clasp is tapered to correspond, so that the tendency is always for the clasp to tighten around the joint (National Tube Co.).

Kutter's formula.—A formula for estimating the flow of water in rivers and canals, and sometimes modified for estimating the flow through long pipes with low velocity and entrance head (Webster).

Laccolith; laccolite.—(Geology.)—A mass of intrusive igneous rock, of approximately circular outline and lenticular cross-section, with a flat base, which has been forced between strata so as to raise the overlying beds in the form of a dome (La Forge).

Laid length.—The length measured after pipe is placed in position. It includes such items as gaskets or space between ends of pipe in coupling or the insertion of bell and spigot joint or the central ring of C. J. hub (National Tube Co.).

Laminae.—The thinnest separable layers or sheets in stratified rocks, whether (1) original planes of decomposition, parallel or oblique to the general stratification, or (2) in rarer usage, planes of cleavage transverse to stratification (Standard).

Lamination.—Fine sedimentation planes within strata (Lowe).

Lamp.—Any device employing a flame, incandescent wire or the like, for furnishing an artificial light, or a similar device for heating, as in laboratory use (Standard).

Lampblack.—A product obtained directly from natural gas or oil by burning the latter under plates or rolls.

Lamp-burning test.—A test for illuminating oils in which the oil is burned in a standard lamp under standard conditions (Delbridge).

Lamp oil.—See illuminating oils and kerosene.

Land.—To definitely fix the casing at a given depth in the hole (Sands).

Latch jack.—A fishing tool designed to catch the bail of a bailer (Sands).

Latent heat.—The thermal equivalent of the energy expended in melting a unit mass of a solid or vaporizing a unit mass of a liquid; or conversely, the thermal equivalent of energy set free in the process of solidification or liquefaction (Webster).

Lateral.—Belonging to the sides or to one side (Roy. Com.).

Law of mass action.—The law that the chemical action of a reacting substance is proportional at any moment to its active mass (Webster).

Law of superposition.—The law that underlying strata must be older than overlying strata where there has been neither inversion nor overthrust. Upon this law all geological chronology is based (Standard).

Lay.—The direction or twist of the wires and strands composing a rope (Sands).

Layer.—A bed or stratum of rock (Buckley).

Lease.—A contract for the possession and profits of lands for a determinate period, in consideration of a recompense of rent. The instrument by which such grant is made. A piece of land leased for mining purposes.

Lease methods.—(1) **Block:** a method of leasing oil lands whereby a fixed royalty rate on all oil produced up to a certain amount is called for, after which a lower rate is charged. (2) **Class:** a method of leasing oil lands whereby the wells are classified at the beginning and a different rate used with each well. The classification is based on the ratio of the value of the product to the cost of production. (3) **Period:** a method of leasing oil lands whereby the royalty rate is changed by some definite amount when the well produces less than a specified quantity per day or other given unit of time. (4) **Uniformly digressive:** a method of leasing oil lands whereby all the production less than a certain amount per week pays no royalty.

Leaser.—A man employed to procure leases.

Left regular lay cable.—A cable with individual wires laid to the right to form strands and strands laid to the left to form cables (Sands).

Legs.—The two sides or wings of a saddle reef or anticline (Power).

Lensing.—A thickening of the bed, causing a variation in the stratigraphic interval.

Lenticular.—Shaped approximately like a double convex lens. When a mass of rock thins out from the center to a thin edge all around, it is said to be lenticular in form (Roy. Com.).

Lessee.—The one to whom the lease is granted.

Lessor.—The one who grants the lease.

Level.—An instrument used for determining points of equal elevation or differences in elevation.

Lie key.—A tool on which boring rods are hung when being raised or lowered in a bore-hole (Barrowman).

Lift.—In drilling, the vertical movement of the drilling tools (Sands).

Light carbureted hydrogen.—See Marsh gas.

Lignite.—A brownish-black coal in which the alteration of vegetal material has proceeded further than in peat but not so far as in sub-bituminous coal (Fay).

Ligroin.—A term rather loosely applied. It may denote a refined petroleum distillate of boiling point 120° to 135° C., but is occasionally applied to lower boiling fractions, such as benzoline; in general, it is held to be another name for light petroleum. Russian ligroin is a naphtha having a boiling point of 100° to 120° C. and a specific gravity of 0.707 to 0.722 at 15° C. (Bacon).

Limb.—One of the two parts of an anticline or syncline on either side of the axis. See Legs.

Limestone.—The general name for sedimentary rocks composed essentially of calcium carbonate (Kemp).

Line of dip.—The line of greatest inclination of a stratum to the horizon (Thompson).

Line pipe.—A special brand of pipe that employs recessed and taper-thread couplings, and usually greater length of thread than Briggs' standard. The pipe is also

subjected to higher test (National Tube Co.). It differs from standard pipe in that it is always lap-welded, the couplings are longer, and the ends of both couplings and tubes are always reamed (Sands).

Liner.—A short string of casing (Sands).

Liquefied petroleum gas.—Liquefied condensates from natural gas or from casing-head gas of oil wells, made either by the compression or absorption process, alone or blended with other petroleum products, and having a vapor pressure at 100° F. (90° F. from Nov. 1st to March 1st) exceeding 10 pounds per square inch (Towl).

Liquid bituminous material.—Bituminous material which shows a penetration at normal temperature, under a load of 50 grams applied for one second, of more than 350 (Bacon).

Liter; litre.—A measure of capacity in the metric system, being a cubic decimeter, equal to 61.022 cubic inches, or 0.890 Imperial quart, or 0.908 U. S. dry quart, or 1.0567 U. S. liquid quarts. It is equal to 1 kilogram of water at maximum density (Webster).

Litharge.—Protoxide of lead or plumbous oxide, the lowest oxide of lead (PbO) (A. D. Smith).

Lithologic.—Pertaining to lithology or the study of rocks. Pertaining to rock character (Ransome).

Litmus paper.—A paper dipped into a solution of litmus, and used to test solutions in order to determine whether they are acid or alkaline (Standard). Acid turns it red; alkali turns it blue.

Live steam.—Steam direct from the boiler, having its full power of expansion, distinguished from exhaust steam, which has been deprived of its available energy (Webster).

Lock nut.—(1) A nut placed on a parallel-threaded portion of pipe at a joint in order to stop leaks by means of a grummet, gasket or packing.

(2) Also used to make a joint where the long screw or lock nut nipple has been run through the tank, the lock nuts being used to wedge up against the tank on either side (National Tube Co.).

Locke level.—A hand level for determining differences in elevation.

Locked-wire rope.—A rope with a smooth cylindrical surface, the wires of which are drawn to such shape that each one interlocks with the other and the wires are disposed to concentric layers about a wire core instead of in strands. Particularly adapted for haulage and rope-transmission purposes (C. M. P.).

Log.—A record of drilling, giving in detail the color, nature, thickness, and contents of the formations encountered (Sands).

Long ton.—A ton of 2240 pounds avoirdupois. Equal to 1016.06 kilograms (Webster).

Look-box.—A device providing means for observing the stream of distillate from a petroleum still. It is placed between the condenser and the manifold through which the stream is diverted into proper tanks.

Low dip.—Dip of less than 5 per cent, which is best recorded as so many feet per mile.

Lubricants.—Materials, especially oils, greases, and graphite, used to decrease friction.

Lubricating.—A technical term for coating the walls of a well with mud-laden fluid to stop water or gas flow.

Lubricating greases.—Lubricants employed to some extent on account of their easy and, in some cases, economical application, consisting of solutions of lime-soaps or lime-alkali-soaps in mineral oils; mixtures of wool-grease, tallow, alkali soaps, etc., with mineral oil; or, in the case of axle or wagon greases, of lime-soaps, rosin oil, lignite-tar, coal-tar, oils, magnesium silicates (talcum), mica, etc. (Bacon).

Lubricating oils.—In petroleum refining, lubricating oils may be the distillates passing over after gas oils, almost to the end of the distillation until still wax appears, also petroleum residues not rendered too sticky by asphalt or other resinous matter.

Lubricites.—A word used by M. E. Wadsworth to include all mineral lubricants or anti-friction materials (Power).

Lungmotor.—A trade name for a mechanical device for inducing respiration in cases of asphyxia, drowning, electrical shock, etc. It consists of two parallel cylinders with pistons externally connected so that a stroke in one direction exhausts the lungs through one cylinder while the other cylinder fills with air, oxygen, or both, and a stroke in the opposite direction inflates the lungs with the air or oxygen, and discharges the foul gases drawn from the lungs (Fay).

Main shaft.—In drilling, the band-wheel shaft (Sands).

Make-up.—To screw together, as drill pipe or a string of tools (Sands).

Making hole.—Depth gained in drilling wells (Fay).

Malleable iron.—Cast iron made from pig iron of the proper kind, so treated as to render it capable of being bent or hammered to a limited extent without breaking, that is, to render it malleable. Its strength is above that of cast iron. The treatment is known as annealing (National Tube Co.).

Mandrel socket.—A well tool for straightening out the top of casing, etc., within a well, consisting of a lemon-shaped swedge within a cone or bell-mouth, by means of which the casing is worked to a circular shape. Also useful for straightening a lost sand pump, etc., so that the dogs may enter (National Tube Co.).

Marsh gas.—Methane; same as fire-damp. More accurately used in recent years to describe the natural gas exuding from marshes and also obtained from drilling near the surface, as distinguished from "deep gas," "oil gas," "petroleum gas," obtained from deep wells and indicative of the presence of oil. By analysis, marsh gas is distinguished from oil gas by containing significant amounts of carbon dioxide (10 per cent or more) and other impurities. Large proportions of nitrogen may be found in either marsh gas or deep gas. When large proportions of both carbon dioxide and nitrogen are present in natural gas from shallow wells, it may safely be assumed to come from the decomposition of surface organic matter.

Mastic.—A mixture of bituminous material and fine mineral matter, for use in highway construction and for application in a heated condition (Bacon).

Masut; mazout.—A Russian petroleum product; crude oil deprived of volatile, light substances by exposure to air; specific gravity above 0.880; flash-point about 70° C. (Bacon).

Matheson and Dresser joint.—A combination joint in which a Dresser leak clamp of special form is used to reinforce a Matheson joint. Its special advantage is that is allows repair without shutting off the service pressure. Much used on natural gas lines on service pressures up to 250 pounds and at times up to 500 pounds, and on pipes 16 inches outside diameter and less—and even on 20 inches outside diameter (National Tube Co.).

Matheson joint.—A wrought pipe made by enlarging one end of the pipe to form a suitable lead recess, similar to the bell end of a cast-iron pipe, and which receives the male or spigot end of the next length. Practically the same style of a joint as used for cast-iron pipe (National Tube Co.).

Matrix.—The material which forms a cushion, or binder, for use in the construction of pavements (Bacon).

Mechanical efficiency.—The ratio between the actual brake horse-power, as shown to be developed by the brake or other similar device for measuring the power developed, and the total or gross power obtained, as shown by the indicator diagram (Goldingham).

Melting point.—The degree of temperature at which a solid substance melts or fuses, best determined by placing a particle of the solid in a capillary tube sealed at one end, strapping this tube to a thermometer, which is then immersed in a liquid, the temperature of which is gradually raised. The point at which the particle of solid becomes liquid is noted. Pure substances usually melt instantly.

Mercaptans.—Sulphur compounds, analogous to alcohols, in which sulphur has replaced oxygen. They are colorless liquids, with a strong repulsive odor like garlic.

Meta.—(1) A prefix denoting a form of certain inorganic acids derived from the ortho, or ordinary form by the loss of one molecule of water.

(2) A substance isomeric with, or otherwise closely related to the one to whose name the prefix is attached.

(3) Certain benzene derivatives, in which two substances added to the benzene nucleus are separated by a CH group.

Metamorphism.—(Geology.)—Any change in the texture or composition of a rock, after its induration or solidification, produced by exterior agencies, especially by deformation and by rise of temperature. The processes and results of cementation and of weathering are not ordinarily included (La Forge). The most important agents are **heat, moisture,** and **pressure.**

Meter; metre.—(1) An instrument, apparatus, or machine for measuring fluids, gases, electric currents, grain, etc., and recording the results obtained; as, a gas **meter,** a water **meter,** an air **meter.**

(2) The fundamental unit of length in the metric system, originally defined as one ten-millionth of the distance on the earth's surface from the pole to the equator; now as the distance between two lines on a certain metallic rod preserved in the archives of the International Metric Commission at Paris (Standard). It is equal to 39.37079 inches.

Methane.—The initial member of the marsh gas or paraffin (C_nH_{2n+2}) series of hydrocarbons. See Marsh gas.

Metric system.—A system of weights and measures depending upon the meter, in which the original factors are derived from the meter. The system includes measures of length, of which the **meter** is the unit; measures of surface, of which the **are** is the unit; measures of capacity, of which the **liter** is the unit; and weights, of which the **gram** is the unit (Standard).

Metric ton.—One thousand kilograms, equal to 2204.6 avoirdupois pounds (Webster).

Mexican fluxes.—The flux produced from Mexican petroleum; it is differentiated from paraffin fluxes, semi-asphaltic fluxes, and asphaltic fluxes by marked characteristics, such as the fact that it contains a high percentage of sulphur, yields a high ash-free residual coke, and contains 2 per cent or more of hard paraffin scale, while only 80 per cent of it is soluble in 88° Bé. naphtha, as compared to over 90 per cent in the case of the other residuals (Bacon).

Micrometer.—An instrument by which exceedingly minute measurements may be made.

Migration.—Wandering of oil and gas from one position to another, due to gravity, water, or capillarity. It is frequently shown by change in character of the oil.

Mineral.—A mineral is a body produced by the processes of inorganic nature, having a definite chemical composition and, if formed under certain favorable conditions, a certain characteristic molecular structure, as exhibited in its crystalline form and other physical properties. A mineral must be a homogeneous substance, even when minutely examined by the microscope; further, it must have a definite chemical composition, capable of being expressed by a chemical formula (Dana). The term mineral, when employed in a conveyance, is understood to include every inorganic substance that can be extracted from the earth for profit, whether it be solid, as rock, fire clay, the various metals and coal, or fluid, as mineral waters, petroleum, and gas (Horace Creek Land and Mine Co. *vs.* Midkiff (W. Va.), 95 S. E. Rept., p. 27).

Mineral land.—Land more valuable for its deposits of stone, or whatever is recognized as mineral, than for agriculture (McGlenn *vs.* Wienbrocer, 15 Land Decisions, p. 375; Berry *vs.* Central Pacific R. R. Co., 15 Land Decisions, p. 464; United States *vs.* Iron Silver Min. Co., 128 United States, p. 673).

Mineral oil.—Crude petroleum and its products. Also, loosely, liquid petrolatum.

Mineral resin.—An oxygenated organic substance occurring in nature partially or wholly saponifiable.

Mineral right.—The ownership of the minerals under a given surface, with the right to enter thereon, mine, and remove them. It may be separated from the surface ownership, but if it is not so separated by distinct conveyance, the latter includes it (Raymond).

Mineral seal oil.—A cut between kerosene distillate and gas-oil, widely used as a solvent oil in gasoline absorption processes. It is used largely in signal lamps and for light-house illumination (A. D. Smith).

Mineral tar.—A viscid variety of petroleum (Power). Tar derived from various bituminous minerals, as coal, shale, peat, etc. Shale tar (Standard).

Miner's inch.—The miner's inch of water does not represent a fixed and definite quantity, being measured generally by the arbitrary standard of the various ditch companies. Generally, however, it is accepted to mean the quantity of water that will escape from an aperture 1 inch square through a 2-inch plank, with a steady flow of water standing 6 inches above the top of the escape aperture, the quantity so discharged amounting to 2274 cubic feet in twenty-four hours (Hanks). Inasmuch as the miner's inch is a local term, "the flow of water shall be expressed in cubic feet per second, and where it is desirable, for local reasons, to use the term 'miner's inch' it shall represent a flow of 1½ cubic feet per minute" (W. H. Shockley, Bull. 92, Min. and Met. Soc. of America, Jan. 1916, p. 32).

Miners' sunshine.—A soft grade of paraffin wax used by miners for burning in lamps.

Miner's wax.—A refined paraffin wax with a melting point of 118° to 120° F.

Mining.—Act or business of making mines or working them (Webster). The processes by which useful minerals are obtained from the earth's crust, including not only underground excavations but also workings; it also includes both underground and surface deposits (Burdick *vs.* Dillon, 144 Fed. Rept., p. 739). Also applied to the producing of petroleum and natural gas.

Mix (in cold settling).—A solution of filtered stock in naphtha, so proportioned that the amorphous wax originally present in the stock will be largely precipitated at the refrigeration temperature employed (A. D. Smith).

Mixture.—A commingling in which the ingredients retain their individual properties or separate chemical nature; if chemically combined it is a compound (Standard).

Molecule.—The smallest part of a substance that can exist separately and still retain its composition and characteristic properties; the smallest combination of atoms that will form a given chemical compound (Rickard).

Mond gas.—A variety of semi-water gas, having typically a calorific value of about 145 B.t.u. per cubic foot. Ammonia is often collected as a by-product (Webster).

Monoclinal.—(1) Dipping only in one direction, or composed of strata so dipping; as, a monoclinal ridge; a monoclinal flexure. Sometimes improperly called uniclinal.

(2) An abrupt downward flexure of nearly horizontal strata without any corresponding bend to form an anticline or syncline.

(3) Loosely, any series of strata dipping in one direction only, as an isocline (Standard).

Monoclinal bulge.—Domes that rise with apparently irregular spacing on a monoclinal slope (Clapp).

Monocline.—See under Homocline.

Mother oil.—Crude petroleum from which other crudes have been derived.

Motor.—One who or that which produces or imparts motion or mechanical power. Specifically, a machine for producing or causing motion, especially one that acts by transmitting some other kind of energy into mechanical energy, or the energy of position into that of motion; a prime mover, as a steam engine, windmill, water wheel, or reversed dynamo (Standard).

Mud.—(1) Moist and soft earth, or earthy matter, whether produced by rains on the earth's surface, by ejections from springs and volcanoes, or by sediment from turbid waters; mire (Century).

(2) In drilling, the emulsion made by the mixture of water with the drillings in the drill-hole.

Mud-bit.—A chisel-like tool used for boring wells through clay (Webster).

Mud-laden fluid.—The emulsion of mud and water which is circulated during rotary drilling (Sands).

Mud lubricator.—A device by which mud is used to smother a strong gas flow (Sands).

Mudoff.—In rotary drilling, to seal off, with the drilling mud, a formation containing water, gas or oil (Sands).

Mud sill.—The lowest sill of a structure, usually imbedded in the soil; the lowest sill or timber of a house, bridge, dam or derrick (Webster).

Mud socket.—A device used on drilling tools to clean mud or sand out of a well (Webster).

Mud volcano.—An outburst of water, sometimes heated, discharging mud into the air, occasionally with a rumbling noise, and sometimes forming a conspicuous cone many feet in height (Clapp).

Naphtha.—Crude naphtha is the term generally used for the first cut made in the distillation of petroleum. It may or may not require treatment with acids or steam distillation, to meet trade demand as gasoline. This depends upon its color, odor, and distillation characteristics.

The term naphtha is also applied to the less volatile portion obtained on redistilling benzine. It is good practice to confine the designation " refined naphtha " to mixtures of light hydrocarbons intended for some purpose that requires a very good odor, such as dry-cleaning, varnish-making, soap-making, etc. " Solvent naphtha " is usually obtained from coal tar. " Green naphtha " is one of the

condensates obtained in the fractionation of crude shale oil. Also the name for Russian crude petroleum.

Naphtha gas.—Illuminating gas charged with the decomposed vapor of naphtha (Standard).

Naphthenic acids.—Normal oxidation products of the naphthene series of hydrocarbons. Naphthenes oxidize thus more readily than do other hydrocarbon series and consequently naphthenic acids are usually found in petroleums of the Russian type which are high in hydrocarbons of the naphthene group.

The rank odor of these compounds has thus far prevented their utilization.

Nascent state.—The condition of an element at the moment of liberation from a compound, marked, as in the case of hydrogen or oxygen, by a chemical activity greater than the ordinary (Webster).

Natural gas.—A mixture of gaseous hydrocarbons found in nature; in many places connected with deposits of petroleum, to which the gaseous compounds are closely related (U. S. Geol. Survey).

Needle valve.—At times called needle-point valve. A valve provided with a long tapering point in place of the ordinary valve disk. The tapering point permits fine graduation of the opening (National Tube Co.).

Neutral oils.—(1) Oils carrying paraffin, which are obtained by the steam-distillation of paraffin-base petroleum after the second-grade illuminating oil has been run off. Neutral oil carrying paraffin is known as " wax distillate " (Bacon).

(2) Lubricants of medium viscosity and fire test, usually filtered, obtained by reduction of pressed distillate from wax oil or wax distillate (A. D. Smith).

Nipple.—A tubular pipe fitting usually threaded on both ends and under 12 inches in length. Pipe over 12 inches is regarded as cut pipe (National Tube Co.).

Nitrocellulose.—A term used to include the various nitrates of cellulose, such as guncotton, nitrolignine, nitrocotton, nitrojute, etc. The most common of these is nitrocotton (Du Pont).

Nitrocotton.—A chemical combination of ordinary cotton fiber with nitric acid. It is explosive, highly inflammable, and in certain degree of nitration, soluble in nitroglycerin (Du Pont).

Nitrogelatin.—Same as gelatin dynamite (Standard).

Nitroglycerin.—The product of the action of nitric acid and sulphuric acid on glycerin. It is not properly a nitro compound, as the name implies, but is a nitric ester of glycerin (Brunewig, p. 253). It is an oily substance about one and one-half times as heavy as water (Sp. Gr. 1.6), is almost insoluble in water, and is used as a principal or active ingredient in dynamite, gelatin dynamite, etc. It is not used commercially in the form of a liquid, except for " shooting oil wells " (Du Pont).

Nitronaphthalene.—Obtained by the action of nitric acid on naphthalene and used to deprive mineral oils of their fluorescence.

Nitrosubstitution.—The act or process of introducing by substitution the radical nitryl (NO_2) in place of one or more replaceable hydrogen atoms, as in an organic compound (Standard). **Nitrosubstitution** compounds are used in the manufacture of certain kinds of explosives.

Nitrosulphuric acid.—An exceedingly corrosive mixture of one part of nitric acid mixed with two parts by weight of sulphuric acid. It is used in the manufacture of nitroglycerin (Standard).

Normal benzine.—Benzine of the specific gravity 0.695 to 0.705 at 15° C., and boiling point from 65° to 95° C., proposed in Germany for the purpose of detecting and estimating asphalt in petroleum (Bacon).

Normal pressure.—Standard pressure, usually taken to be equal to that of a column of mercury 760 mm. in height (Webster). Approximately 14.7 pounds per square inch.

Normal solution.—A solution containing one gram-equivalent of the solute in one liter of solution (Fay).

Normal temperature.—In laboratory investigations, 20° to 25° C., or 68° to 77° F.

Occlude.—To take in and retain in pores or other openings, to adsorb; used particularly with respect to the adsorbing of gases by certain substances which do not thereby lose their characteristic properties, as charcoal, iron, etc.

Occurrence.—In geology, the existence or presence of any thing or phenomenon in any special position, or in any specified relations to other objects or phenomena, as the occurrence of gold in a vein (Standard).

Odometer.—Instrument used for measuring distance passed over by any wheeled vehicle and also in topographical surveying in regions traversed by roads. The wheel is generally 10 feet in circumference and is made with great care. Used in preparation of county maps (Century).

Oil.—An unctuous combustible substance, liquid, or at least easily liquefiable on warming and soluble in ether but not in water.

This term includes (*a*) fatty oils and acids; (*b*) essential oils, mostly of vegetal origin, such as eucalyptus, and turpentine, and (*c*) mineral oils, such as petroleum products, including lubricating oils (Min. and Sci. Press).

Oil car.—See Tank car.

Oil engine.—An internal combustion engine adapted for the use of an oil product and occasionally crude oil.

Oil field.—A district containing a subterranean store of petroleum of economic value (Webster).

Oil flotation.—A process in which oil is used in ore concentration by flotation. See Flotation process.

Oil fuel.—Refined or crude petroleum, shale oil, residuum, tar, or similar substances, used as fuel (Century).

Oil gage.—An instrument of the hydrometer type arranged for testing the specific gravity of oils; an oleometer (Century). Also a device for measuring oil in a tank.

Oil gas.—Illuminating gas, or heating gas, made by distilling oil in closed retorts (Standard).

Oil-gas tars.—Tars produced by "cracking" oil vapors in the manufacture of oil gas (Bacon).

Oil-line pump.—A pump for forcing crude petroleum along a pipe-line (Standard).

Oil of paraffin.—A colorless to yellowish, limpid oil, having a specific gravity of about 0.880 and not boiling below 360°. It is composed principally of high-boiling hydrocarbons of the (C_nH_{2n+2}) series, and is obtained from the petroleum fraction boiling above 300°, the product being refined and decolorized. It is used in pharmacy in ointments, and as the base for various coatings insoluble in water (Bacon).

Oil pits.—See Hand-dug wells.

Oil pool.—An accumulation of oil in sedimentary rock that yields petroleum on drilling. The oil occurs in the pores of the rock and is not a pool or pond in the ordinary sense of these words (U. S. Geol. Survey).

Oil pulp.—An aluminum soap, consisting of aluminum salts of the fatty acids, chiefly oleic, palmitic, and stearic acids. It is dissolved in mineral oil to form an oil thickener (Bacon).

Oil rights.—A term under which the ownership of oil under a given tract of ground is transferred from one owner to another by lease or purchase. In leasing or purchasing oil property it is more usual to lease or purchase both oil and gas rights, though in many cases the two substances are disposed of separately.

Oil sand.—Porous sandstone from which petroleum is obtained by drilled wells (Fay). All porous oil strata are commonly termed oil sand by the driller.

Oil saver.—An appliance affixed to the mouth of an oil well when the latter requires deepening, although still flowing in small quantities. It consists of a cap fitted to the top of the well casing and having a lateral pipe communicating with a reservoir for the oil (Mitzakis).

Oil shale.—Shale containing such a proportion of hydrocarbons as to be capable of yielding mineral oil on slow distillation (Gresley). Includes all rocks which, because of their chemical or physical properties or owing to the conditions of sedimentation under which they were formed, may be petrographically classed as shale and which will yield volatile hydrocarbons under any method of treatment (Day). See Shale, Shale oil, Pumpherston shale, Kerogen, and Bituminous shales.

Oil smellers.—Fakirs who profess to be able to indicate where oil-bearing strata are to be found, and locate places for successful well boring, by the sense of smell or by other non-technical methods.

Oil spring.—A spring of petroleum, maltha, or other hydrocarbon, with or without admixture of water (Fay).

Oil string.—The string of casing or tubing which is let down to the oil sand and through which the oil flows to the surface (Sands).

Oil switch.—An electric switch or circuit breaker, in which the break occurs under oil, used for opening circuits of very great power and very high voltage.

Oil well.—A dug or bored well from which petroleum is obtained by pumping or by natural flow.

Oil-well packing.—A packing inserted between the pipe and the interior surface of the boring in an oil well to keep surface water from the sides of the hole from running into the well and to prevent oil in some wells from being forced out around the pipe by a pressure of gas (Century).

Oil zone.—A formation that contains capillary or supercapillary voids, or both, that are full of petroleum that will move under ordinary hydrostatic pressure (Meinzer).

Olefiant gas.—Ethylene. See Heavy carbureted hydrogen.

Oleo resin.—The viscous to semi-solid and usually light-colored solutions of true resins in essential oils, either obtained from, or constituting, the saps of certain plants and trees (Bacon).

Once-run oil.—The second and last cut of the crude shale oil when first distilled.

Open hole.—The part of a well which is uncased (Sands).

Open sand.—Sandstone, with sufficient voids to provide good storage for oil.

Operator.—The person, whether proprietor or lessee, actually operating a mine or oil well or lease.

Optical character.—The designation as to whether optically positive or optically negative (A. F. Rogers). Said of minerals.

Optical constants.—In optical mineralogy, the indices of refraction, axial angle, extinction angle, etc. (A. F. Rogers).

Option.—A privilege secured by the payment of a certain consideration for the purchase or lease of mining or other property, within a specified time, or upon the fulfillment of certain conditions set forth in the contract (Fay).

Orchard-heating oil.—A product from California petroleum, used in the orange and lemon groves to prevent frost from injuring the trees. Also termed smudge oil.

Ore.—A natural mineral compound, of the elements of which at least one is a metal. The term is applied more loosely to all metalliferous rock, though it contain the metal in a free state, and occasionally to the compounds of non-metallic substances, as sulphur ore (Raymond). Also material mined and worked for non-metals, as pyrite is an ore of sulphur (Webster).

A mineral of sufficient value, as to quality and quantity, to be mined with profit (Ihlseng).

A mineral, or mineral aggregate, containing precious or useful metals or metalloids, and which occurs in such quantity, grade, and chemical combination as to make extraction commercially profitable (Robert Peele, Min. and Met. Soc. of America, Bull. 64, p. 257).

Ore in sight.—A term frequently used to indicate two separate factors in an estimate, namely: (*a*) ore blocked out, that is ore exposed on at least three sides within reasonable distance of each other; (*b*) ore which may be reasonably assumed to exist, though not actually blocked out. These two factors should in all cases be kept distinct, because (*a*) is governed by fixed rules, while (*b*) is dependent upon individual judgment and local experience. The expression "ore in sight" as commonly used in the past appears to possess so indefinite a meaning as to discredit its use completely. The terms "positive ore," "probable ore," and "possible ore" are suggested (Min. and Met. Soc. of America, Bull. 64, pp. 258 and 261).

Organic.—(Chemistry.)—Pertaining to or designating a branch of chemistry, treating in general of the compounds produced in plants and animals, and of carbon compounds of artificial origin; contrasted with inorganic (Webster).

Orientation.—(Surveying.)—The rotation of a map (or instrument) until the line of direction between any two of its points is parallel to the corresponding direction in nature (Webster).

Oronite.—An enamel paint for protecting metal surfaces from the action of hot vapors (Fay).

Ortho.—A prefix used in chemistry in two ways: (1) to denote what may be called a normal or ordinary compound as distinguished from others which are not normal; (2) to denote two adjacent positions in the benzene ring and occasionally in other rings (Webster).

Osmosis.—A kind of diffusion which takes place between two miscible fluids separated by a permeable partition, as an animal membrane, and which tends to equalization on the two sides of the partition (Webster).

Osmotic pressure.—The unbalanced pressure which gives rise to the phenomena of diffusion and of osmosis, as in a solution in which there are differences of concentration (Webster).

Ostatki.—In the Russian petroleum industry, the residuum left in the still after the distillation of the kerosene. It is a thin liquid of a specific gravity of about 0.905 to 0.912. It contains but little paraffin, and yields lubricating oils of good quality.

Only a small proportion of it is worked up for this purpose, the remainder being utilized for fuel.

Outage.—The difference between the full and rated capacity and the actual contents of a barrel, tank, or tank car.

Outcrop.—(1) The coming out of a stratum to the surface of the ground. That part of a stratum which appears at the surface (Basset).

(2) To crop out; to come out to the surface of the ground, as strata (Webster).

Oval socket.—In well-boring, a fishing tool used to slip over the ends of broken and lost poles, to grip so as to recover them (National Tube Co.).

Over and short.—Balance between calculated stocks of oil and oil actually on hand, due to expansion, contraction, losses or faulty measurement. Balance between bookkeeper's statement and oil on hand.

Overburden.—The waste which overlies the good stone in a quarry (Raymond). Worthless surface material covering a body of useful mineral (Skinner).

Overhead charges.—Those general charges or expenses which can not be charged up as belonging exclusively to any particular part of the work or product (Webster).

Overhead products.—All products which are taken off from an oil still in vapor form (A. D. Smith).

Over-point.—In the process of distillation, the temperature at which the first drop comes over into the flask.

Overshot.—A fishing tool used in rotary drilling (Sands).

Overthrust fault.—A reverse fault with low dip, or large head (Lindgren).

Overturned.—Having been tilted past the vertical and hence inverted in outcrop; said of folded strata and of the folds themselves (La Forge).

Pace counter.—Instrument for approximate measuring of distances, by pressing lever for every other step taken.

Packer.—A device used to shut off water between casing and tubing and the wall of the hole, between two strings of casing, or between casing and tubing. Based on the vertical compression and the horizontal expansion of a flexible material, such as rubber (Sands).

Packing.—A general term relating to a yielding material employed to effect a tight joint. A common example is the sheet rubber used for gaskets. The term is also applied to the braided hemp or metallic rings used in some joints, that allow considerable or incessant motion (National Tube Co.).

Paddy.—A well drill having cutters that expand on pressure (Standard).

Painters' naphtha.—Deodorized naphtha, of gravity 58° to 60° Bé., sometimes employed in paints.

Paint thinner.—See Turpentine substitutes.

Paleography.—A description of a region as to its rock characteristics. Geography of former lands and seas (Clapp).

Para.—A prefix meaning beside or nearby, used in chemical terms (Standard). The prefix **para** is used in two ways in chemistry. (1) It is used to denote a substance which is a polymer of another substance: Examples, paracyanogen and paraaldehyde, which are polymers of cyanogen and aldehyde respectively.

(2) It is used to denote any two opposite carbon atoms in the benzene ring and occasionally any two diametrically opposed carbon or other atoms in heterocyclic six-membered rings.

Paraffin.—(1) A white, waxy substance, resembling spermaceti, obtained from petroleum, coal tar, wood tar, etc.

(2) A white, waxy, inodorous, tasteless substance, harder than tallow, softer than wax, with a specific gravity of 0.890. It is insoluble in water, is indifferent to the most powerful acids, alkalies, and chlorine, and can be distilled unchanged with strong sulphuric acid. Warm alcohol, ether, oil of turpentine, olive oil, benzol, chloroform, and carbon disulphide dissolve it readily. It can be mixed in all proportions with wax, stearine, palmitine, and resins (Bacon). Paraffin is found native, as in ozokerite and hatchettite, also in peat and bituminous coal, and is contained in numerous oils, as petroleum, from which it is separated by distillation (Standard).

(3) The name of the series of (C_nH_{2n+2}) hydrocarbons chiefly comprising American petroleums.

Paraffin-asphalt petroleum.—A combination of paraffin-base and asphalt-base petroleum.

Paraffin-base petroleum.—Crude oil which carries solid paraffin hydrocarbons and practically no asphalt.

Paraffin butter.—A variety of native paraffin used in making candles (Standard). Also one of the past products of petroleum distillation.

Paraffin coal.—A light-colored bituminous coal used for the production of oil and paraffin (Mitzakis).

Paraffin distillate.—A crystalline product ready for pressing, used as the base for paraffin wax and paraffin oils. This base for paraffin wax and paraffin oils should be distinguished from wax distillate produced by steam reduction of fuel oil, the former being a crystalline product ready for pressing, the latter a semiamorphous substance requiring additional rerunning (A. D. Smith).

Paraffinic acid.—($C_{24}H_{48}O_2$).—It is obtained by the oxidation of paraffin by concentrated nitric acid or by chromium trioxide mixture. It is also easily oxidized by air when warm and exposed to light.

Paraffin oil.—(1) Lubricating oil made by the dry distillation method.

(2) A name for liquid petrolatum (Bacon).

Paraffin scale.—Crude paraffin wax.

Paraffin " slack " wax.—A term applied to the soft wax obtained from the hot or cold pressing of paraffin distillate or wax oil (A. D. Smith).

Paraffinum liquidum.—The medicinal petroleum of the British Pharmacopœia. Specific gravity, 0.885–0.89; boiling point above 360° F. In the refining of Russian petroleum, the finest quality of perfumery oil is termed " paraffinum liquidum " and for pharmaceutical purposes is often subjected to a final distillation (Bacon).

Paraffinum molle.—According to the British Pharmacopœia, a petroleum product corresponding to the vaseline of the United States Pharmacopœia; it is described as having a melting point of 95° F. (Bacon).

Paraffin wax.—A colorless, more or less translucent mass, crystalline when separating from solution, without odor or taste, and slightly greasy to the touch, consisting of a mixture of solid hydrocarbons, chiefly of the methane series. Refined paraffin wax is pure white, the better grade being of 25 color in melted condition, and showing in solid state a translucent rather than an opaque whiteness. It is also practically odorless and tasteless, containing usually less than 0.5 per cent of oil and sulphur moisture. The U. S. Pharmacopœia describes it (paraffinum) as a colorless, more or less translucent mass; crystalline when separating from

solution, without odor or taste, and slightly greasy to the touch, consisting of a mixture of solid hydrocarbons chiefly of the methane series; usually obtained by chilling and pressing the distillates from petroleum having high boiling points, and purifying the solid press cake so obtained. Its characteristics are given as follows: insoluble in water or cold alcohol; slightly soluble in absolute alcohol; readily soluble in ether, petroleum, benzine, benzene, carbon disulphide, volatile oils, and in warm fixed oils (A. D. Smith).

Peat tar.—A tar obtained from the distillation of peat. The distillates obtained contain from 2 to 6 per cent of tar (Bacon).

Peening.—The act or process of hammering sheet metals with the peen of a hammer, either to straighten them or to impart a desired curvature (National Tube Co.).

Penetration.—(1) In laboratory investigations of paraffin, waxes, etc., the distance, expressed in tenths of a millimeter, penetrated by a No. 2 cambric needle operated in a machine for the purpose and under known conditions of loading, time, and temperature. The degree of solidity of bituminous materials.

(2) In construction, the entrance of bituminous material into the interstices of the metal of the roadway (Bacon).

Penetration method.—The method of constructing a bituminous macadam pavement by pouring or grouting the bituminous material into the upper course of the road metal before the binding of the latter has been completed (Bacon).

Penetrometer.—A device used to determine the consistency of asphalt, and other bituminous substances, by measuring the distance a standard needle will vertically penetrate a sample of asphalt, when weighted with 100 grams for five seconds at 25° C. (77° F.) (R. G. Smith).

Percussion system of drilling.—See Cable system.

Perfumery oil.—Properly refined Russian perfumery oil possesses a specific gravity of 0.880 to 0.885, is colorless and inodorous, without fluorescence, and does not turn yellow or deposit a sediment after prolonged exposure to direct sunlight. The finest quality is used in pharmacy as " paraffinum liquidum " (Bacon).

Perkins joint.—A joint made up with threaded pipe and coupling, both threaded straight (no taper). One end of the pipe is left square and the other beveled to a knife edge at mid-thickness. Has been used in Baku oil region (National Tube Co.).

Perkins method.—A patented method of cementing oil wells (Sands).

Petrocene.—A product obtained by the distillation of petroleum residue at a red heat, having needle-like crystals of a greenish-yellow color and pearly luster. It is isomeric with anthracene, though unlike it in crystalline form, melting point, and solubility (Bacon).

Petrol.—A variant for petroleum or its derivatives, particularly (in England) gasoline or motor spirit.

Petrolatum.—Semi-solid oil obtained from petroleum by evaporation and filtration, white, slightly yellowish, or yellow. It has a specific gravity of 0.820 to 0.850 at 60° C. and melts at 45° to 48° C. It is soluble in ether, chloroform, benzine, carbon disulphide, slightly soluble in alcohol, and insoluble in water and glycerin. Called also in the trade, by different makers, cosmoline, saxoline, vaseline, petroline, etc. Veterinary petrolatum is a dark-yellow, semi-solid mass; it is essentially crude (unpurified) petrolatum (Bacon). **Extra light amber petrolatum:** this and the grade following are equivalent to a greater or less extent to the multiplicity of preparations sold as soft paraffin, petroleum jelly, paraffin jelly, "cosmoline," "vaseline," "unguentum petrolei," etc. As produced from Penn-

sylvania products, the amber grades of petrolatum contain hydrocarbons from $C_{16}H_{34}$ up to probably $C_{22}H_{46}$, and also contain members of the higher olefine series, such as $C_{16}H_{32}$,$C_{17}H_{34}$, etc. They conform in all respects to the tests prescribed for petrolatum by the U. S. Pharmacopœia. Petrolatum is insoluble in water, scarcely soluble in cold or hot alcohol, or in cold absolute alcohol, but soluble in boiling absolute alcohol, and readily soluble in ether, chloroform, petroleum, benzine, benzene, and fixed or volatile oils. **White petrolatum:** or petroleum album of the U. S. Pharmacopœia, defined as a colorless mixture of hydrocarbons, chiefly of the methane series, obtained by distilling off the lighter and more volatile portions from petroleum, and purifying the residue. A white unctuous mass, of about the consistence of an ointment, transparent in thin layers, completely amorphous, without odor or taste. In other respects, white petrolatum has the characteristics of, and should respond to the tests given under petrolatum. (A. D. Smith).

Petrolatum (liquid).—A colorless to slightly yellowish, transparent liquid, possessing a specific gravity of 0.840 to 0.940 at 25° C. (usually 0.84–0.87). It is soluble in ether, chloroform, carbon disulphide, benzine, benzol, boiling alcohol, but is scarcely soluble in cold or warm alcohol, and is insoluble in water (Bacon).

Petrolatum liquidum.—The medicinal high-boiling petroleum oil of the United States Pharmacopœia.

Petrolatum stock.—This material, the base for all light petrolatum, varies from light yellow to dark green in color, according to the nature of the materials used in its manufacture. Its usual properties are approximately as follows: 32° to 34° Bé. gravity; 400° to 410° flash; 40 to 50 viscosity at 212° F. It should possess only a faint odor, be sweet to the taste, and show freedom from suspended impurities (A. D. Smith).

Petrolene.—A liquid hydrocarbon mixture obtained from bitumen or asphalt.

Petrolenes.—That portion of the asphalt which is dissolved by 86° Bé. naphtha. (R. G. Smith).

Petroleum.—(1) An oily, inflammable, liquid mixture of numerous hydrocarbons, chiefly of the paraffin series, found in the earth. The petroleums found in different areas vary widely in composition and appearance (U. S. Geol. Survey).

(2) The name commonly given to the liquid oils found in the earth. Petroleum is usually a homogeneous intersolution of many oils which are compounds of carbon and hydrogen (D. T. Day).

Petroleum is a mineral, and the same may be said of salts and phosphates, and of clay containing alumina and other substances in the earth (Union Oil Co. in re 23 Land Decisions, p. 229). Lands chiefly valuable for the deposits of petroleum contained therein are mineral lands within the meaning of the mining laws, and subject to location and entry as such (Union Oil Co. in re 25 Land Decisions, p. 357; Tulare Oil and Min. Co. *vs.* So. Pac. R. R. Co., 29 Land Decisions, p. 271; Chrisman *vs.* Miller, 197 U. S., p. 320). Deposits of petroleum oil come within the definition of mineral character of land, and are sufficient to exclude such land from a railroad grant if discovered before patent issues (So. Pac. R. R. Co. in re Land Decisions, p. 265). Oil or petroleum lands are mineral lands within the meaning of that term in this grant (Burke *vs.* So. Pac. R. R. Co., 235, U. S., p. 669).

Petroleum acids.—See Naphthenic acids.

Petroleum asphalt.—Commercial name for the residues of asphalt-base petroleums.

Petroleum benzine.—A cut in the redistillation of crude naphtha.

Petroleum briquet.—A briquet made of a mixture of petroleum, soft soap, resin, and soda-lye wash.

Petroleum car.—See Tank car.

Petroleum coke.—The residue obtained by the distillation of petroleum. It usually shows the following composition: volatile and combustible matter, 5 to 10 per cent; fixed carbon, 90 to 95 per cent; ash from a trace to 0.3 per cent; sulphur, from 0.5 per cent to 1 per cent. On account of its purity it has found application in metallurgical processes and in making battery carbons and carbon pencils ("electric carbons") (Bacon).

Petroleum ether.—A volatile, inflammable liquid used as a solvent for caoutchouc, oils, etc. (Webster). Some refiners have applied this designation to the products ranging in specific gravity from 0.590 to 0.686, that is, cymogene, rhigolene, and gasoline. Russian petroleum ether varies in specific gravity from 0.650 to 0.660 at 15° C. (Bacon). Also frequently applied to naphtha.

Petroleum furnace.—A furnace for burning petroleum, as under a steam boiler (Century).

Petroleum naphtha.—A term which is loosely employed; often applied to the first fraction obtained on distillation of crude oil or to any low-boiling petroleum product.

Petroleum pitch.—See Pitch.

Petroleum refining.—The process of separating crude petroleum into its various commercial products and the purification of these products.

Petroleum spirit.—A volatile liquid obtained by the distillation of petroleum (Webster). A term variously used, but sometimes applied to a petroleum distillate of a density of 0.71 to 0.74 and a boiling point of 90° to 140° C. It is used as a solvent (Bacon).

Petroleum still.—A still for separating the hydrocarbon products from crude petroleum (Standard).

Petroleum tailings.—See Residuum.

Petroliferous.—Containing or yielding petroleum (Standard).

Petroline.—A solid substance, analogous to paraffin, obtained in the distillation of Rangoon petroleum. Also a term applied to a Scottish burning-oil having a flash point of 126° F. (Bacon).

Petrolize.—To treat or impregnate with petroleum or a petroleum product (Webster).

Photogene.—A trade name for a shale-oil distillate, of specific gravity from 0.72–0.80 and a boiling point from 145–150° C. It is used as an illuminating oil. (Bacon).

Photometer.—A machine used to determine the candle power of kerosene or the intensity of light.

Piezometer.—An instrument for experiments on the elasticity of liquids; the latter are subjected to an increase of pressure and the resulting diminution of volume is observed (Webster).

Pin.—See Joint.

Pipe.—A long conducting passage, usually a line of tubes; any long tube or hollow body; especially one that is used as a conductor of water, oil, or other fluids, as drain pipe, water pipe, etc. (National Tube Co.).

Pipe dog.—A hand tool that is used to rotate a pipe whose end is accessible, consisting of a small, short steel bar whose end is bent at a right angle to the handle, and then quickly returned, leaving only enough space between the jaws to slip over the wall of pipe (National Tube Co.).

Pipe grab.—A clutch for catching and raising a well pipe (Standard).

Pipe grip.—In steam and pipe-fitting, an implement consisting of an iron bar with a curved end and provided with a chain of square links to hook on to the jaws of the curved end. See Chain tongs (National Tube Co.).

Pipe jacks.—A device for raising or lowering the end of a pipe when screwing it to another (Towl).

Pipe-line.—A line or conduit of pipe, sometimes many hundred miles long, through which petroleum is conveyed from an oil region to a market or to reservoirs for refining (Standard). A line of pipe with pumping machinery and apparatus for conveying a liquid or gas (U. S. Min. Stat., pp. 1068–1073).

Pipe prover.—An apparatus for testing the tightness of a pipe-line or system, usually by hydraulic pressure. (Standard.)

Pipe thread.—A thread employed in connection with wrought pipe. The standard thread is the Briggs', which has an angle of 60° between its sides, slightly rounded at top and bottom and which has a taper (National Tube Co.).

Pipe tongs.—A hand tool for gripping or rotating pipe (National Tube Co.).

Pipe wrench.—A wrench whose jaws are usually serrated and arranged to grip with increasing pressure as the handle is pulled. There are many forms, such as alligator Stillson, Trimo, etc. (National Tube Co.).

Pitch.—A term loosely used to denote:

(1) The residuum from the distillation of rosin oils.

(2) The residuum remaining in the retorts after the distillation of coal tar.

(3) The residuum, somewhat similar to the above in appearance, remaining after the distillation of crude petroleum.

(4) Natural asphalts, particularly that from the Asphalt or Pitch Lake in Trinidad.

Pitometer.—In hydraulics, an instrument for autographically recording variations of flowing water. It consists essentially of two Pitot tubes, one pointed upstream and one downstream (Webster).

Pitot tube.—A tube bent at right angles, which, when inserted in a current of gas, receives the force of the current and measures its velocity by the rise of water in the vertical branch.

Plane-table.—A simple surveying instrument by means of which one can plot the lines of a survey directly from the observation. It consists of a drawing board on a tripod, with a ruler, the ruler being pointed at the object observed (Webster).

Plot.—A map, usually without detail, serving as a guide for more detailed geological or topographical work.

Plug.—When used without qualification, it always means, in the pipe trade, the ordinary plug or pipe plug that has an exterior pipe thread and a projecting head (usually square) by which it is screwed into the opening of a fitting, etc. (National Tube Co)

Plugging.—The stopping of the flow of water, gas or oil in a well, usually by means of a wooden plug or core or by cement or clay.

Plugs.—Necks of igneous rock rising through sedimentary rocks, often giving rise to oil accumulations.

Pneumercator.—An instrument used for measuring the contents of tanks, reservoirs, standpipes, etc.

Pocket.—(Usually gas, oil, or water pocket).—A cavity or an especially porous lens-like bed of small dimensions which yields a sudden but temporary flow of oil, gas, or water.

Polariscope.—An instrument for studying the properties of, and examining substances by polarized light (Webster).

Polarization.—The process by which ordinary light is changed into polarized light. The plane at right angles to the plane of transverse vibration is called the plane of polarization (Dana).

Polarized.—Changed from the ordinary state, in which the transverse vibrations occur in all planes passing through the line of propagation, to a state in which they are in a single plane; said of light under certain conditions, especially when passed through a doubly refracting crystal (La Forge). Polarized light is used to distinguish minerals, particularly colorless, transparent ones, under the microscope.

Polarizer.—That one of the two Nicol prisms in a polarizing microscope through which the light passes before reaching the mineral section which is being examined (La Forge).

Pole drill.—In well-boring, a system where a rigid connection is used between the drilling tools and the reciprocating beam (National Tube Co.).

Polycyclic.—A term applied to compounds, chiefly of carbon and hydrogen, in which the carbon atoms are represented as grouped in two or more rings.

Polymeric.—Having the same elements united in the same proportions by weight, but with different molecular weights (Webster).

Polymerize.—To change into another substance having the same elements in the same proportions, but with a higher molecular weight (Webster).

Pool.—A belt of oil-producing territory (Webster). A deposit of petroleum whose limits are defined by dry holes.

Porosity.—The state or quality of being porous. The volume of pore space expressed as a percentage of the total volume of the rock mass (Fay).

Portable drilling machine.—A light, compact, modified cable-tool drilling outfit mounted on wheels (Sands).

Pot-hole.—A hole extending below the wearing course in a pavement (Bacon).

Pour.—To transfer from one position to another by inclining the container.

Pour test, or point.—The lowest temperature at which an oil will pour or flow when chilled without disturbance, under definite specified conditions (Delbridge).

Power.—Mechanism for pumping several wells by means of lines extending from a central station to each of a group of wells.

Term used in the oil-fields to denote a central power plant by which several wells are pumped (Sands).

Power distillate.—The untreated kerosene condensates and still heavier distillates down to 28° Bé. from Mid-Continent petroleum, used as fuel in internal combustion engines (Bacon). Heavy-end power distillates are cut from eastern and Mid-Continent crudes between kerosene distillate and gas oil. It is usually set aside for rerunning, although often sold under a variety of names for light-horse-power engine fuel (A. D. Smith).

Power gas.—Any gas made for producing power, as for driving gas engines (Webster).

Precipitate.—A substance in a liquid thrown down in solid form from solution, by the addition of some other substance in solution. When a substance held only mechanically in suspension in a liquid settles to the bottom, it is called sediment.

Preheat.—To heat previously; as an oil to be subsequently distilled, or gas and oil to be used as fuel.

Preheaters.—Any form of apparatus in which heat is applied to a material prior to its injection into the main heating apparatus; usually by heat that would otherwise be wasted (R. B. Day).

Pressed distillate.—The oil coming from the presses when paraffin wax is recovered.

Pressure filter.—A filter in which the liquid to be filtered is forced through filtering material by a pressure greater than its own weight in the filter (Century).

Prime white oil.—A kerosene of prime white color, that is, intermediate in color between water white and standard white (Bacon).

Producer gas.—A combustible gas to be used for fuel, for driving gas engines, for making illuminating gas, etc., made by forcing steam and air through a layer of incandescent fuel, as coke, the resulting gas consisting largely of carbon monoxide and nitrogen (Webster).

Production.—That which is produced or made; any tangible result of industrial or other labor (Standard). The yield or output of an oil or gas well, or a group of wells.

Productive.—Capable of producing.

Prospect hole.—Any shaft, pit, drift, or drill hole made for the purpose of prospecting mineral-bearing ground.

Prospecting.—Searching for new deposits; also, preliminary exploration to test the value of deposits already known to exist.

Proven, proved.—As applied to oil property, land bounded by producing wells.

Pseudo.—As a prefix, implies something false; but its meaning is modified by the subject to which it applies (Emmons).

Puking.—Used in refinery parlance to denote the boiling over of a still, in which the crude charge mixes with distillate and generally contaminates the contents of a run-down tank (A. D. Smith).

Pull.—To withdraw the casing of a well. Also used to describe the process of cleaning a pumping well which consists of removing the pump rods and tubing, cleaning out, or repairing the pump, tubing, or rods.

Pulmotor.—A mechanical device designed to perform artificial respiration in cases of asphyxia, electric shock, drowning, etc., by exhausting the lungs and filling them with oxygen-enriched air.

Pump.—Any of numerous devices or machines for raising, transferring, or compressing liquids or gases by suction or pressure or both. To work or raise water, etc., with a pump (Webster).

Pumpage.—The amount raised by pumping; as, the pumpage of an oil well (Standard).

Pumper.—An instrument or machine used in pumping. An oil well that has to be pumped (Webster). A workman who looks after a pumping well or group of wells.

Pump fist.—The lower end of a plunger case of a pump (Gresley).

Pumpherston shales.—Scottish oil-shales, that yield, on the average, 16 to 22 gallons of crude oil per ton, together with 50 to 60 pounds of ammonium sulphate. Their particular feature is their richness in nitrogen (Bacon.)

Pumping jack.—A device used over relatively shallow wells for operating the pump by lines connected with a central power.

Pumping-out pan.—A shallow, open-top form of condenser box (A. D. Smith).

Pump kettle.—A convex perforated diaphragm fixed at the bottom of a pump table to prevent the entrance of foreign matter; a strainer (Century).

Pump rod.—The rod or system of rods connecting the walking beam of a derrick or jack at the surface, with the pump piston below.

Pump-rod plates.—Spear plates; strips or plates of iron bolted to wooden pump-rods at the joints, for the purpose of making the connection (Barrowman).

Pump station.—A pumping plant stationed at necessary intervals along the course of a pipe-line for the purpose of forcing the oil through the lines.

Pycnometer.—A vial of fixed capacity used to determine the specific gravity of fluids (R. G. Smith).

Pyrene.—A hydrocarbon, $C_{16}H_{10}$, from coal tar. More frequently used as the trade name for carbon tetrachloride, which is used as a fire extinguisher.

Pyrobituminous.—Yielding bituminous products on heating, as coal (Webster).

Pyrometer.—Any instrument for measuring degrees of heat, especially above those indicated by the mercurial thermometer (Webster).

Pyrometry.—The art of measuring degrees of heat; the art of using a pyrometer (Webster).

Pyronaphtha.—Heavy illuminating oil and solar oil from Russian petroleum, having a light-yellow color and specific gravity of 0.840 to 0.860. However, the product to which the name of pyronaphtha is given, is usually of a lower gravity than solar oil.

Radiation.—(1) Emission and diffusion of rays, as of light or heat (Webster).

(2) Term in surveying; one of four ways of locating a station. The other three are intersection, resection, and traversing. A calculation based on the use of the plane-table.

Radical.—An atom or element, or a group of elements, that is the chief constituent of the molecules of a given compound, a group that will not decompose in the ordinary chemical reactions to which a compound is liable; more specifically, a group of atoms acting as a single element in a compound and incapable of independent existence, as NH_4 (ammonium) in NH_4Cl (ammonium chloride) or C_2H_5 (ethyl) in C_2H_5OH (ethyl hydrate or alcohol) (Standard).

Radioactive.—Capable of emitting, spontaneously, rays consisting (at least in part) of material particles traveling at high velocities (Webster).

Raky system.—A percussion drilling system designed by Engineer Raky, a Russian. Although it is at present considered a little old-fashioned, it is still in use in some parts of the Taman Peninsula and Crimea (Mitzakis).

Rasp.—An instrument used at oil wells for reducing the size of the box or collar on lost tools, in preparation for the use of fishing tools (Mitzakis).

Rat-hole.—(1) A slanting hole about 25 feet in depth, into which the grief stem may be lowered for lubricating or adjusting the swivel.

(2) To prepare for rotary drilling by drilling with a small bit, leaving a seat for casing (Sands).

Rat-holing.—Reducing the size of the bore-hole and feeling ahead (Sands).

Ravine.—A small topographic or structural depression relatively greater in length than width.

Reaction.—The action of one chemical substance upon another, accompanied by the formation of a new substance.

Reagent.—Any substance which, by reason of its capacity for taking part in certain reactions, is used in detecting, examining, or measuring other substances, in preparing material, etc. (Webster).

Ream.—In drilling, to enlarge a hole already drilled, to permit the entrance of casing.

Reamer.—(or underground reamer).—A tool with expanding cutters or lugs, used for enlarging the bore-hole.

Réaumur.—Thermometer scale with 0° as the freezing point of water and 80° as the boiling point. Degrees Réaumur = Degrees Centigrade $\times \frac{4}{5}$ = (Degrees Fahrenheit $-32) \times \frac{4}{9}$.

Reconnaissance.—A preliminary geological survey.

Recovered acid.—Sulphuric acid which has been used for treating oil and recovered for repeated use.

Recovered oils.—Used lubricating oils which are collected and used again after purification.

Recovery.—The total amount of products obtained in any refining operation compared with the original amount of material before refining.

Reduce.—(1) To deprive of oxygen. (2) To distill off lighter oils to obtain oils of greater gravity or viscosity.

Reduced oil.—Oil from which the more volatile hydrocarbons have been eliminated by partial evaporation, usually by steam.

Reducer.—A fitting having a larger size at one end than at the other (National Tube Co.).

Reducing still.—A still of the " cheesebox " or horizontal type, equipped with perforated bottom steam coils (A. D. Smith).

Reducing taper elbow.—A reducing elbow whose curved body uniformly decreases in diameter toward the small end (National Tube Co.).

Reducing tee.—Any tee having two different sizes of openings. It may reduce on the run, or branch (National Tube Co.).

Reducing valve.—A spring or lever-loaded valve, similar to a safety valve, whereby a lower and constant pressure may be maintained beyond the valve (National Tube Co.).

Refine.—To free from impurities.

Refinery.—A plant, including apparatus, for refining, or purifying metals, oils, etc.

Refining.—Freeing from impurities. Reducing to a fine unmixed or free state. Does not include blending.

Refraction.—A change of direction which takes place when a ray of light passes from one medium to another of different density (Power).

Refractive index.—An index used for the detection of rosin in mineral oils.

Refractometer.—An instrument for determining the index of refraction of a mineral.

Regional, or normal, dip.—The direction and the average degree of inclination of the strata which persists over a large area, in contradistinction to local reversals of such a normal inclination.

Reins.—The links of a pair of jars (Sands).

Rerun oil.—Oil which has been redistilled.

Resection.—Term in surveying; one of four ways of locating a station. The others are radiation, intersection, and traversing.

Reservoir.—Rock stratum so composed and so arranged structurally as to have large oil-containing capacity.

Residual.—Characteristic of, pertaining to, or consisting of residuum. Remaining after the removal of certain constituents of the oil-mixture.

Residue.—The solid matter remaining after the extraction of the oil from crude material. In a standard laboratory distillation, the amount of original liquid remaining in the distilling flask when the distillation is completed (Delbridge).

Residuum.—The thick, viscous residue obtained by the distillation of crude petroleum after gasoline, kerosene, and sometimes heavier distillates have been removed.

Resin.—The generic term covering saponifiable materials found in oils, with the exception of fatty and sulphuric acids. Erroneously applied to solid bitumens. Also applied to secretions from certain plants or trees. Resins are frequently the products of oxidation or polymerization of terpenes.

Resinous.—Resembling resin.

Retort.—A vessel in which substances are subjected to distillation or decomposition by heat. A retort is distinguished from a still in that it is more often used for the treatment of solid or semi-solid substances.

Return bend.—A 180° bend. Usually a fitting having inside threads. Often applied to a bent pipe. Always means the fitting unless otherwise specified (National Tube Co.).

Reversal.—A dip in the direction opposite to the normal dip (Lahee).

Rhigolene.—The most volatile liquid fraction obtained in the distillation of petroleum.

Rifled pipe.—A pipe used for conveying heavy oils. The pipe is rifled with helical grooves which make a complete turn through 360° in about 10 feet of length (National Tube Co.).

Rig.—A derrick, with its engine house, etc. necessary to run it, used for boring, and afterwards pumping an oil well; also, the derrick itself (Webster).

Rig irons.—The steel or cast-iron appliances necessary to install and operate the bull wheel, calf wheel, band wheel, pitman, and walking beam of a rig (Sands).

Rigging up.—Drillers' term designating the operation which embraces the installation of the boiler, engine, tools, and machinery and establishing a supply of fuel and water (Sands).

Right regular lay cable.—A cable with individual wires laid to the left to form strands and strands laid to the right to form the cable (Sands).

Road-binders.—Asphalt, cold tar, or residuum used to consolidate the rock fragments on the surface of roads.

Rock.—Strictly, any naturally formed aggregate or mass of mineral matter, whether coherent or not, constituting an essential and appreciable part of the earth's crust. Ordinarily, any consolidated or coherent and relatively hard, naturally formed mass of mineral matter; stone (La Forge).

Rock asphalt.—Sandstone or limestone naturally impregnated with asphalt (Bacon).

Rock drill.—See under Drill.

Rock gas.—Natural gas.

Rod guide.—An appliance, attached to the drilling rod in oil wells, that serves to prevent the rod from oscillating or knocking against the sides of the bore-hole (Mitzakis).

Rod wax.—A light-yellow, pasty mass consisting of an emulsion of high-boiling oils with solid hydrocarbons; it collects in considerable quantities around the rods and casing in some of the Pennsylvania wells. Also called sucker-rod wax (Bacon).

Rodman, or rodsman.—One who carries a surveyor's leveling rod (Standard).

Roily oil.—Crude oil that has formed a more or less complete emulsion with water (Redwood).

Rope drilling.—Drilling in the ground with a bit attached to the end of a rope, to which a twisting motion is given. Sometimes called jump drilling, as the rope with the bit is raised and dropped (Fay).

Rope grab.—A tool for recovering ropes lost in the bore-hole. Also known as a rope spear.

Rope knife.—A tool used for cutting the drilling rope in the hole (Sands).

Rope socket.—The part of a string of tools connected to the drilling line.

Rope spear.—A fishing tool with prongs to engage a lost rope or line.

Rosin.—The resinous constituent of the oleo-resin exuded by various species of pine, and known in commerce as crude turpentine.

Rotary.—The turntable used to rotate the pipe in a rotary rig (Sands).

Rotary hose.—Flexible pipe connecting the slush pump to the swivel (Sands).

Rotary shoe.—A casing shoe with a serrated edge, used in rotary drilling (Sands).

Rotary system.—(Of drilling.)—The method of drilling which depends for its effectiveness on a rotating, auger type of bit, and a constant circulation of mud to remove the drillings and to plaster and consolidate the walls of the hole (Sands).

Royalty.—The amount paid by the lessee, or operator, to the owner of the land or mineral rights, based on a certain per cent of total oil or gas production. Gas royalty is frequently a fixed yearly rental. This is occasionally true of oil royalty.

Run.—(1) Oil taken from or by a pipe-line. Applied to oil piped from one place to another; as pipe-line runs from wells. The amount of oil taken from producers' tanks by a pipe-line during a specified time, as a day or month. **Refinery runs:** Total amount of oil fed to a still during a specified time.

(2) To lower casing into a drilled hole and land it at the bottom (Sands).

Runback.—Pipes through which the condensate is returned to the still instead of being drawn off.

Run-down tanks.—Tanks in which distillation products are first received; receiving tanks (A. D. Smith).

Saddle flange.—A flange shaped for bolting on a convex surface.

Saline or salt dome.—A dome-like structure formed in rock strata, the core or central portion of which is rock salt. Found in the Gulf Coast fields and often forming reservoirs for oil.

Sand—(1) Separate grains or particles of detrital rock material, easily distinguished by the unaided eye, but not large enough to be called pebbles; also a loose mass of such grains, forming an incoherent arenaceous sediment.

(2) (Geology.)—Any loose or moderately consolidated bed consisting chiefly of sand; often used in the plural, even in the name of a single deposit (Fay). Specifically, sandstone; a technical usage in petroleum regions (Standard).

Sand line.—In well-boring, a wire line used to lower and raise the bailer or sand pump which frees the bore-hole from drill cuttings (National Tube Co.).

Sand pump.—A cylinder with a valve at the bottom, lowered into a drill hole from time to time to take out the accumulated slime resulting from the action of the drill on the rock (Raymond).

Sand reel.—A drum, operated by a friction drive from the band wheel, used to raise or lower the sand pump or bailer (Sands).

Sandstone.—Any rock formed of coherent or cemented sand (La Forge). Asphaltic sandstone is a loose-textured sandstone containing asphalt (U. S. Geol. Survey).

Saponification.—Conversion into soap; the process in which fatty substances form soap, by combination with an alkali. (Rickard).

Saponification number.—The number of grams of potassium hydroxide required to saponify 1 gram of the substance (Delbridge).

Saponifier.—Any compound, as a caustic alkali, used in soap-making to convert the fatty acids into soap (Standard).

Satin-gloss black.—A name for lampblack.

Saturated.—A term applied to those hydrocarbons which do not take on addition products without giving up hydrogen, especially the paraffin or aliphatic (C_nH_{2n+2}) and polymethylene (C_nH_{2n}) hydrocarbons.

Scale.—The incrustation caused in steam-boilers by the evaporation of water containing mineral salts (Raymond). Crude paraffin obtained in petroleum refining by filtering from the heavier oils (Webster).

Scale wax.—A wax that has had all but a small percentage of the oil sweated out.

Scarf.—In the manufacture of pipe, to slightly level or roll down the longitidinal edges of a steel plate to the extent that these edges are to overlap (Speller).

Scarf weld.—A joint that is made by overlapping and welding together the scarfed ends or edges of metal sheets (National Tube Co.).

Scarps.—See Escarpment.

Scleroscope.—An instrument for testing the hardness of materials.

Scout.—A term frequently used for the engineer who makes preliminary examinations of promising mining claims and prospects, as for mineral, coal, oil, etc. (Fay).

Scraper.—See Go-devil.

Scraper-chaser.—One of the men whose business it is to follow the scraper (go-devil) in the petroleum pipes and give instant notice if a clog occurs (Standard). The scraper-chaser follows the pipe-line on the surface and detects the location of the go-devil by sound, especially where pipes are shallow.

Screw conveyor.—An apparatus by which materials may be transported by the action of a helical screw.

Scrubber.—An apparatus for washing and removing ammonia and light hydrocarbons from gas.

Sea drag.—A cone-shaped canvas bag which is attached to an iron ring at the top; used for putting storm oil on the water.

Seal.—To secure against a flow or escape of gas, air or liquid; as, to seal a gas well.

Seal coat.—A final superficial application of bituminous material, during construction, to a bituminous pavement (Bacon).

Sediment.—Any material other than water, which separates by itself below oil in a tank. Foreign matter, usually sand or dirt which settles to the bottom from a liquid.

Sedimentation.—Accumulation or deposition, by water or air, of vegetable or animal deposits of sediment, especially in the formation of sedimentary rocks, either aqueous or of wind-drift variety (Standard).

Seedbag.—A bag filled with flaxseed and fastened around the tubing in an oil well, so as to form, by the swelling of the flaxseed when wet, a water-tight packing, preventing percolation down the sides of the bore-hole from upper to lower strata. When the tubing is pulled up, the upper fastening of the bag breaks, and it empties itself, thus presenting no resistance to the extraction of the tubing (Raymond).

Seep.—A spot where water or petroleum oozes out slowly; a small spring (Webster).

Seepage.—A fluid, or the quantity of it, that has oozed or seeped through porous soil (Webster). An oil spring (Lahee).

Seizing.—The binding of operating parts through failure of lubricants or overheating.

Semi-Diesel engine.—An engine of the Diesel type but differing from the true Diesel in that it requires an external source of heat for ignition and its operation does not follow the Carnot cycle so closely (Goldingham).

Semi-solid bituminous material.—Bituminous material showing a penetration at normal temperature, under a load of 100 grams applied for five seconds, of more than 10, and under a load of 50 grams applied for one second, of not more than 350 (Bacon).

Seneca oil.—Petroleum, early used as a remedy among the Senecas and other Indians (Webster).

Separator.—A machine for separating, with the aid of water or air, materials of different specific gravity. An apparatus for separating the oil mechanically carried over by the vapor in distillation.

Set.—To fix casing definitely in the bore-hole (Sands).

Setting point.—The point or temperature at which a liquid sets or congeals.

Setting up.—A relatively quick change, such as takes place in a bituminous material after its application to a roadway, indicated by its hardening after cooling and exposure to atmospheric and traffic conditions; as opposed to the slower changes occurring gradually and almost imperceptibly (Bacon).

Settled production.—The production of an oil well, which, apart from the normal progressive annual diminution, will last a number of years (Redwood).

Settler.—A separator; a tub, pan, vat, or tank in which a separation can be effected by settling (Century).

Settles to boil.—A refinery expression signifying that the original entrained water in the charge has been nearly distilled off, and the temperature is probably passing 300° F. (A. D. Smith).

Shale.—A fine-grained, fissile, argillaceous, sedimentary rock characterized by rather fragile and uneven laminæ and commonly by a somewhat splintery fracture. Often, but incorrectly, called slate by miners, quarrymen, well-drillers, and others (La Forge).

Shale naphtha.—The naphtha obtained from shale oil.

Shale oil.—Oil occurring in crevices in shale is sometimes known as shale oil. It is poor practice to use the term shale oil in this way, as it should be limited to oil extracted from shale.

Shale spirit.—The lower-boiling fractions obtained in the refining of crude shale oil.

Shaly.—Characteristic of, pertaining to, composed of, or resembling shale; having the characteristic structure and fissility of shale; as, a **shaly** sandstone or limestone (La Forge).

Sheet.—The fabricated steel plates forming a still (A. D. Smith).

Sheet-asphalt pavement.—A pavement composed of a mechanical mixture of asphalt with a carefully graded sand and a mineral filler, such as limestone dust (R. G. Smith).

Shell.—A torpedo used in shooting oil wells. A hard, thin band or layer of rock encountered in well-boring (Redwood).

Shell pump.—A simple form of sand pump or sludger consisting of a hollow cylinder with a ball or clack valve at the bottom, used with a flush of water to remove débris (Webster).

Sheave.—A wheel with a grooved circumference over which a rope is turned, either for the transmission of power or for hoisting or hauling (Chance). Any grooved wheel or pulley (Webster).

Shoe.—The bottom wedge-shaped piece attached to tubing when sinking through quicksand (Power).

Shoe-nose shell.—A cylindrical tool, cut obliquely at bottom, for boring through hard clay (Raymond).

Shoe shell.—A tool used in deep borings for cleaning out the drill cuttings. It has a valve at the bottom, opening upward (Gresley).

Shooter.—In the petroleum industry, one who shoots oil wells with nitroglycerin, to loosen or shatter the oil-bearing formation (Fay).

Shooting.—The act of exploding a charge, usually nitroglycerin, in a drill-hole to shatter the sand and to increase the inflow of oil through the crevices thus formed (Sands).

Shooting needle.—A blasting needle; a metallic rod used in the stemming of a drill-hole for the purpose of leaving a cavity through which the charge may be fired (Century).

Shot.—A term used in geological surveying for a complete instrumental reading, including distance, vertical angle, and direction.

Shot drill.—An earth-boring drill using steel shot as an abrasive. See Adamantine drill (Fay).

Show.—The first appearance of oil from a well; usually noticed as a rainbow on the water from the well. It requires practice to distinguish this rainbow film from the films formed from lubricating oils used in the drilling; also any appearance of oil that is too small to measure in barrels, or too insignificant to produce.

Showings.—Presence in a well, or in the bailings, of small quantities of petroleum, or recognized indications thereof (Sands).

Shutdown.—A term denoting that work has been temporarily stopped, as on an oil well (Redwood).

Shut-in.—A closed well.

Side irons.—The iron or steel parts which make up the bearings for the walking beam and the supports for these bearings (Sands).

Side shot.—A branch traverse made from a more accurately mapped traverse or station. The hand level method is useful in making "side shots."

Side tracking.—Drilling past a broken drill or string of casing which has become permanently lodged in the hole (Sands).

Sink.—To drill or put down a drill-hole.

Sinker bar.—A bar added to the drill tools simply to give the required force to the upward jar. It is never allowed to pound upon the drill (Chance).

Sinker-bar guides.—Bars of iron (usually four) fitted to the drill tools in order to increase their girth and render it impossible for the drill to deviate (Mitzakis).

Sink hole.—A vertical hole worn by water into limestone rocks along a point or fracture. Such a hole is usually connected with an underground channel. The caving-in of the roof may cause more depression and the formation of a pond. The course of a joint marked by a row of sink holes. Also called sink; swallow-hole (Standard).

Sinuous.—Tortuous, serpentine, full of curves, bends, or turns; undulating (Century).

Skelp.—Plates used in making steel pipe (Speller).

Skimming.—The removal of (in addition to the benzine content removed by the topping process) all of the kerosene fraction and often part of the gas-oil (A. D. Smith).

Skimming plant.—A refinery designed and equipped to recover only the light products from crude oil. (See Topping) (A. D. Smith).

Slack barrel.—A specially made barrel for shipping wax. Usually contains 235 to 245 pounds net of wax, 19 to 20 pounds tar (A. D. Smith).

Slack wax.—See Paraffin slack wax.

Sleeve.—A piece of pipe or thimble for covering a joint, or for coupling two lengths of piping (Webster).

Slip.—See under Fault.

Slip socket.—A fishing tool.

Slop oil.—Any liquid product of petroleum which is not up to quality. Slop oils are usually put aside for redistillation (Bacon).

Sludge.—A term applied to the tar from the agitators in the chemical treatment of oil.

Sludge acid.—Impure and dark-colored sulphuric acid that has been used in refining petroleum (Webster).

Slump.—Change in the altitude of an outcropping bed, due to slipping down hill.

Slush pump.—The pump used to circulate the mud-laden fluid in rotary drilling (Sands).

Smudge oil.—A dark distillate of 26° to 28° Bé. gravity, cut from California crude. Used in the citrus belt to prevent damage to trees from frost (A. D. Smith).

Soap stock.—Sweet, light-colored amorphous waxes used in the manufacture of soap and in the saturation of waxed papers (A. D. Smith).

Socket.—(1) A device fastened to the end of a rope, by means of which the rope may be attached to its load; also known as a rope socket.

(2) A fishing tool designed to encircle and grip a solid object (Sands).

Soft pitch.—Pitch showing a penetration of more than 10 (Bacon).

Solar oil.—A name given to a gas-oil from petroleum of the Gulf and Mid-Continent fields; it is generally exported to Great Britain.

Solid bituminous material.—Bituminous material showing a penetration, at normal temperature under a load of 100 grams applied for five seconds, of not more than 10 (Bacon).

Solidified gasoline.—Gasoline converted into jelly, by a process in which stearic acid, having previously undergone prolonged treatment with hydrochloric acid at a high temperature, is dissolved in the gasoline (Bacon).

Solidified petroleum.—The following are two of the best known methods which have been resorted to in attempting to "solidify" petroleum for use in grates: (1) absorption of the oil by a porous material, preferably itself combustible, as dry peat; and (2) the production of a jelly-like emulsion by the addition of soap or of a fatty oil and alkali to form a soap (Bacon). Kerosene is converted into a jelly for convenience in shipping.

Soluble.—Capable of being dissolved in a fluid; dissolvable (Century).

Solute.—The substance dissolved in a solution (Rickard).

Solution.—(1) The change of matter from the solid or gaseous into the liquid state by its combination with a liquid; when unaccompanied by chemical change, called physical solution; otherwise, chemical solution.

(2) The result of such change; a liquid combination of a liquid and a non-liquid substance (Standard).

Solvent naphtha.—Both coal-tar naphtha and wood naphtha are marketed under this name (Bacon).

Spear.—A fishing tool designed to enter a hollow object and expand, thus attaching itself firmly (Sands).

Specific gravity.—The ratio of the weight of a body to that of an equal volume of some standard substance, water in the case of liquids and solids, air in the case of gases; numerically equal to the density (Standard).

Specific heat.—The number of units of heat required to raise a unit of mass of any substance 1° in temperature (Standard). Thermal capacity.

Spent.—Exhausted; deprived of its valuable constituents, chiefly used in shale distillation.

Spider.—A circular iron device, with spaces for serrated slips, which surrounds and grips the casing or drill pipe (Sands).

Spotted.—Irregularly distributed.

Spouter.—An oil well the flow of which has not been controlled.

Spud.—(1) To work the boring tool by means of the bull wheel alone in starting an oil well (Webster). (2) A tool having a long curved blade used to work around and recover tools from a boring well (Standard).

Spudding.—The initial step in drilling, performed with a spudding bit actuated by a jerk line from the wrist pin of the crank (Sands).

Spudding bit.—A broad, dull drilling tool for working in earth down to the rock (Standard).

Squib.—Small charge of powder exploded in the bottom of a drill-hole to spring the rock, after which a heavy shot is fired (Steel). A springing shot. In well-boring, a vessel, containing the explosive and fitted with a time fuse, that is lowered into a well to detonate the nitroglycerin charge (National Tube Co.).

Stabber.—Field term for the man who attends to the alignment of the unscrewed joint with the first screwed joint of the pipe-line (Towl).

Stadia.—A method of determining the distance between two points, consisting in sighting through a telescope containing horizontal cross-hairs (stadia-hairs) located at one of the points, and observing the length of a graduated rod (stadia-rod) which is subtended between the hairs, the rod being located at the second point.

Stadia measurements.—(Engineering.)—A method of measuring distances, extensively employed in the United States. Stadia measurements are based on the geometrical principle that the length of parallel lines is proportional to their distance from the apex of the angle (Century).

Stadia rod.—(Surveying.)—An instrument used with the stadia to measure the distance from the observation point to the place where the rod is positioned.

Stadia tables.—Mathematical tables from which may be found, without computation, the horizontal and vertical components of a reading made with a transit and a stadia rod (Fay).

Stadia traversing.—In mapping, a method practiced by petroleum engineers with a plane-table. This method combines traversing and radiation and is readily applicable to the tracing of outcrops. Stations need to be visited only once; distances and elevations are obtained from direct rod readings.

Stalagmometer.—A tube having a minute orifice in one end for measuring a liquid in drops; a stactometer.

Stand.—A number of " joints," or sections, of pipe or casing. When pipe or casing is let into, or pulled from, a well, several joints (usually three or four) are handled as a unit, or a " stand."

Standard coordinates.—In mathematics, latitude, longitude and height above the mean sea-level are the three coordinates commonly used to define the position of a meteorological station (Century).

Standard pipe.—(1) The standard adopted by the wrought-pipe makers in 1886.

(2) Standard is a term frequently but unfortunately used to indicate a regular or common product (National Tube Co.).

Standard systems.—(Of drilling.)—See Cable system.

Standard-tool drilling-in outfit.—See Dual system.

Stand pipe.—The vertical pipe, rising up along the side of the derrick, joining the slush pump to the rotary hose (Sands).

Standard white.—A kerosene slightly inferior to water white in color and lamp-burning quality (Delbridge).

Starter.—A drill used for making the upper part of a hole, the remainder of the hole being made with a drill of small gage, known as a follower (Bowles).

Station.—(Surveying.)—(1) The place selected for planting the instrument with which an observation is to be made.

(2) A fixed uniform distance (usually the length of a chain of 100 feet, or 66 feet, or half the length of a 20-meter chain) into which a line of survey is divided. The stations are consecutively numbered (Century).

Steam distillation.—Steam introduced into a still during petroleum distillation for two purposes: first, to lower the boiling point of the oils being distilled by adding the vapor pressure of steam, and, second, to minimize cracking.

Stem.—The heavy iron rod to which the bit is attached in deep drilling by the rope method (Steel).

Step or interval.—The vertical interval measured on the rod, subtended between two stadia-hairs. A hitch or dislocation of the strata (Fay).

Stepping.—(Surveying.)—The method of finding the elevation of a point. This calculation is made by moving the bottom stadia-hair to the upper stadia-hair. This process is not accurate and should therefore be used for measuring " side shots " only, and not for control stations.

Still.—An apparatus in which a substance is changed by heat, with or without chemical decomposition, into vapor, which vapor is then liquefied in a condenser and collected in another part of the apparatus (Standard).

Still coke.—The residue left in the still on distillation of crude oil to dryness (Bacon).

Still grease.—The amorphous distillate from the end of the crude oil and heavy oil distillation in the shale-oil industry (Bacon).

Still wax.—The waxy product, usually yellow, indicating the end of a petroleum distillation.

Stirrup.—In drilling, the iron connecting the pitman to the walking beam (Sands).

Stock.—An oil to be finished into some specified product; as, cylinder stock.

Stocks.—Petroleum in storage, awaiting transfer of ownership or utilization. As used by the U. S. Geological Survey: **Producers' stocks** include petroleum held on producing properties (lease storage). **Pipe line and tank farm stocks:** Petroleum

that has been removed from the producing properties but not delivered to refineries or to other consumers and is held on tank farms, in tanks along pipe lines, and in the lines.

Storage.—Facilities for storing oil. May be earthen, wooden, cement, or steel.

Stove distillate.—A stove gasoline before receiving a finishing treatment (Bacon).

Stove gasoline.—Gasoline used for gasoline stoves and for making illuminating gas (Bacon).

Stove-pipe casing.—Light riveted pipe of large diameter, used in starting a well (Sands).

Straight-run pitch.—A pitch run in the initial process of distillation to the consistency desired, with subsequent fluxing (Bacon).

Strap.—A term used in measuring the circumference of a tank by circling with a steel tape. The operation of obtaining the necessary field data for computing the volume of tanks and other receptacles for fluids (A. D. Smith).

Stratified rock.—Rocks deposited in distinct, generally parallel beds. The distinction between the beds is due to differences in the material, or the size of material deposited. An individual bed is a stratum (plural, strata) and the dividing plane is called a bedding plane.

Stratigraphic interval.—The perpendicular distance between the top surfaces, or the bottom surfaces, of any two strata in a formation (Lahee).

Strike.—(1) The course, or bearing, of the outcrop of an inclined bed or structure on a level surface; the direction, or bearing, of a horizontal line in the plane of an inclined stratum, joint, fault, cleavage plane, or other structural plane; it is perpendicular to the direction of the dip (La Forge). Compare trend.

(2) To find oil in drilling a well.

Strike slip.—See under Fault.

String.—A series of well-drilling tools arranged for lowering into the hole.

String, of casing.—A number of steel or iron pipes of a required diameter and with necessary couplings (Sands).

Stringing.—Distributing pipe for a pipe-line along the right of way (Towl).

String rods.—A line of surface rods connected rigidly for the transmission of power; used for operating small pumps in adjoining shafts from a central station (C. and M. M. P.).

Stripping.—The removal by distillation of all the light fractions down to those of lubricating value (A. D. Smith).

Structure.—That part of the geology of a region which pertains to the altitude of the rocks, the nature and amount, if any, of the deformation they have undergone, and the distribution and mutual relations of the structural features (La Forge).

Substratum.—An underlayer or stratum; a stratum, as of earth or rock, lying immediately under another (Standard).

Subsurface mapping.—Contour mapping in which the key bed is below the surface.

Sucker rod.—The pump rod of an oil or artesian well (Chance).

Sucker-rod wax.—See Rod wax.

Sulphonic acids.—Acids obtained by the addition of SO_3 to a hydrocarbon, usually by treatment of an oil with strong sulphuric acid.

Sulphur dioxide.—A colorless gas, SO_2, having the well-known odor of burning sulphur.

Sulphureted hydrogen.—A colorless gas, H_2S, somewhat soluble in water, having a smell of rotten eggs.

Sump-hole.—A small reservoir near the derrick, into which the bailings or drilling mud are discharged. An earth reservoir made by excavating and banking, into which oil from one or many wells is allowed to run.

Sunned oil.—A trade name for crude petroleum, or a product which is sometimes increased in density and fitted for use as a lubricant by exposing it to the sun as a thin layer on the surface of a tank of warm water, the more volatile portions being thus in part removed by evaporation.

Surface.—The top of the ground; the soil, clay, etc., on the top of strata (Barrowman). As used in the conveyance of coal in place, or in the conveyance of land, reserving the minerals, includes not merely the surface within the boundary lines, without thickness, but includes whatever earth, soil, or land lies above and superincumbent upon the coal or mineral reserved (Yander *vs.* Rights, 66 Indiana, p. 319; 32 American, p. 109; Stonegap Colliery Co. *vs.* Hamilton, 89 S. E. Rept., p. 310).

Surface or field mapping.—Opposed to subsurface mapping where the key bed is far below the ground surface.

Surface-tension.—That property, due to molecular forces, which exists in the surface film of all liquids and tends to bring the contained volume into a form having the least superficial area. The thickness of this film amounts to less than a thousandth of a millimeter and is considered to equal the radius of the sphere of molecular action, that is, the greatest distance at which there is cohesion between the two particles. Particles lying below this film, being equally acted on from all sides, are in equilibrium as to forces of cohesion, but these in the film are, on the whole, attracted inward, and tension results (Webster). As used in the flotation process, the contractile force at the surface of a liquid whereby resistance is offered to rupture (Rickard).

Surfacing.—(1) The crust or pavement.

(2) Constructing a crust or pavement.

(3) Finally finishing the surface of a roadway with a bituminous material (Bacon).

(4) Treating the surface of a roadway.

Swab.—(1) A rod provided with a plunger, used to clean the dirt out of line pipe (Towl).

(2) A device for producing oil from a well, consisting essentially of a plunger, fitted with a check valve in the bottom, which forces the column of oil out of the casing (Sands).

Sweated scale wax.—The crude gray or nearly white oil- and moisture-free wax coming from the sweaters before final filtration for semi-refined grades (A. D. Smith).

Sweating.—The separation of paraffin oil from paraffin wax by partial fusion. The separation of liquid and amorphous wax from solid crystalline paraffin by gradual application of heat (A. D. Smith).

Swedged.—Reduced in diameter by use of blacksmith's swedges or swages (National Tube Co.).

Swedged nipple.—A nipple that has one end smaller than the other; a reducing nipple (National Tube Co.).

Sweet crude.—Crude oil containing little or no sulphur (A. D. Smith).

Sweetening still.—A still in which distillates or other petroleum products are improved in odor (A. D. Smith).

Swivel.—In oil-well drilling, a short piece of casing having one end belled over a heavy ring, and having a large hole through both walls, the other end being threaded (National Tube Co.).

Synclinal axis.—(Geology.)—The central line of a syncline, toward which the beds dip from both sides (La Forge).

Syncline.—A fold in rocks in which the strata dip inward from both sides toward the axis. The opposite of anticline (La Forge).

Synthesis.—(Chemistry.)—The act or process of making or building up a compound by the union of simpler compounds or of its elements (Webster).

Tailings.—The inferior leavings or residue of any product; foots, bottoms; also a shortened term for wax tailings or gum, the last distillate passing off before coking of dry-run crude or tar.

Tank.—A large vessel or receptacle, made of wood, metal, or concrete, for the storage of oil, gas or other fluid.

Tankage.—The act or process of storing oil, etc., in a tank. The price charged or paid for storage in a tank. The capacity of a tank or tanks (Century).

Tank car.—A cylindrical metal tank mounted on underframe and trucks. The car is a container as well as a vehicle of transportation (Towl).

Tanker.—An oil-tank ship or barge.

Tank station.—Tanks located along a pipe-line.

Tank steamer.—A steamer in which oil is transported in bulk lots.

Tankstrapper.—One who measures the capacity of tanks, a gager.

Tank truck.—A truck having a tank for carrying liquids or gases.

Tap.—A tool used for cutting internal threads (National Tube Co.).

Taper rope.—A rope that has a gradually diminishing diameter from the upper to the lower end. The diameter of the rope is decreased by dropping one wire at a time, at regular intervals. Both round and flat ropes may be tapered. Such ropes are intended for deep-shaft hoisting, with a view to proportioning the diameter of the rope to the load to be sustained at different depths (C. M. P.).

Tar.—A thick, brown to black, viscous liquid obtained by distillation of wood, coal, peat, and other organic materials and having a varied composition according to the temperature and material employed in obtaining it (Webster). Soft pitch or thickened petroleum, found in cavities of some limestones (Roy. Com.). Loosely applied to any thick, sticky oil residue. In oil distillation, the substance called tar is closely allied to fuel oil. It represents a strictly dry-run product—the intermediate from which paraffin distillate was distilled before the general adoption of tower stills (A. D. Smith).

Tar distillate.—Distillate from a tar or residuum still.

Tar plug.—A plug located in or near the bottom of a still for pumping out the residuum remaining after distillation (A. D. Smith).

Tar well.—A receptacle in which is collected the tarry liquid which separates from the gas when it leaves the condensers (Century).

Tee.—A fitting, either cast or wrought, that has one side outlet at right angles to the run. A single outlet branch pipe (National Tube Co.).

Telescopic hand level.—Like the Locke level; but also has lenses and stadia-hairs.

Tell-tale flanges.—Observation or testing openings in an oil still (A. D. Smith).

Temper.—To dry fuller's earth at a temperature sufficient to remove all of its hydroscopic moisture and most of its water of crystallization, although it is undesirable to overheat to such an extent as to completely volatilize the last traces of moisture (A. D. Smith).

Temperature.—A condition with respect to heat or cold, especially as indicated by the sensation produced or by the thermometer or pyrometer; degree of heat or cold (Webster).

Temperature coefficient.—A coefficient expressing a quantitative relation between change of temperature and the consequent variation of some other quantity (Webster).

Temper screw.—Part of a drilling rig used to regulate the force of blow of the drill bit (National Tube Co.).

Test.—A reaction or reagent used to recognize or distinguish any particular substance or constituent.

Thermal capacity.—See Specific heat.

Thermal conductivity.—Capability of conducting heat; the quantity of heat that passes in unit time through a unit area of a plate whose thickness is unity when its opposite faces differ in temperature by one degree (Webster).

Thermal efficiency.—The ratio of the heat utilized as compared to the total heat units contained in the fuel consumed (Goldingham).

Thermal unit.—A unit chosen for the comparison, or calculation, of quantities of heat, as the calorie or the British thermal unit (Webster).

Thermodynamics.—That branch of the theory of heat that treats of the relations between heat and mechanical work (Standard).

Thermometer.—Any device for measuring temperature. See also Pyrometer.

Thermostat.—An automatic device for regulating temperature by utilizing the expansion of solids, liquids, or gases, subjected to heat, as in opening or closing the damper of a furnace, regulating the supply of gas, etc. (Webster). A self-acting apparatus for regulating temperature by the unequal expansion of bodies.

Thickened oils.—Mineral oils thickened by dissolving in them small amounts of unvulcanized rubber or of aluminum soap; they are intended for certain lubricating purposes.

Thief.—A device which permits taking a sample from a definite predetermined location in the body of the material sampled (Delbridge).

Tintometer.—An instrument used for determining the color of oils.

Tong key.—The sharp steel projection in the tong which grips the pipe (Towl).

Tongs.—The field term for wrenches used to screw up pipe, particularly pipe of large diameter (Towl).

Tool dresser.—The driller's assistant at an oil well; a junior driller.

Tool extractor.—An implement for grasping and withdrawing boring tools when broken or detached in a bore, as of an oil well, etc. Also called tool grab (Standard).

Topographic high.—Frequently used in the oil-fields to indicate the higher elevation regardless of age; opposed to topographic low which indicates a lower elevation (Fay).

Topographic low.—See Topographic high.

Topography.—(1) The configuration of the earth's surface, including relief, drainage, culture, etc.

(2) The science of surveying the physical features of a district or region and the art of delineating them on maps.

(3) The physical features of a district or region, such as are represented on maps, taken collectively; especially the relief and contour of the land (La Forge).

Topping.—The removal by distillation of the comparatively small percentage of benzine or light engine distillate from the heavier crudes, i.e., the removal of the "tops" (A. D. Smith).

Tops.—The light distillate from a topping plant. It contains the gasoline fraction of crude oil.

Top water.—Water which enters an oil or gas well from a sand above the productive sand. Compare Bottom water; Edge water (U. S. Geol. Survey Bull. 658, p. 44).

Tour.—A term, used in oil-well drilling, which means the same as "shift" in other mining operations. Also spelled tower.

Tower still.—A still provided with, or connected to, one or more separating or dephlegmating towers, affording selective condensation of vapors (A. D. Smith).

Trace.—An amount that can be detected but is not large enough to be measured.

Transit, or transit theodolite.—A surveying instrument with the telescope mounted so that it can be transited (Fay).

Translucent.—Admitting the passage of light, as milk quartz, but not capable of being seen through (Roy. Com.).

Traverse.—In mapping, (1) to make a traverse survey; (2) a line surveyed across a plot of ground.

Traverse survey.—A survey in which a series of lines, joined end to end, are completely determined as to length and azimuth.

Treating.—The art of purifying petroleum intermediates by agitation with chemicals, or by physical absorbents, in a specially constructed type of apparatus known as an agitator or washer (A. D. Smith).

Trend.—See Strike.

Trenton.—Of, pertaining to, or designating a division of the North American Silurian formation, highly developed in the Appalachian region and in the interior (Standard).

Triangle of error.—Term used in surveying by resection. A small triangle formed by a miscalculation—but which may be corrected.

Triangulation.—The operation and immediate result of measuring (ordinarily with a theodolite) the angles of a network of triangles laid out on the earth's surface by marking their vertices (Century).

Trinidad asphalt.—The heaviest of the native asphalts. A dull black material which melts at a relatively low temperature. It breaks with a conchoidal fracture. It is known commercially as lake and land asphalt, depending on whether it is obtained from the large lake on the Island of Trinidad, or from the overflow covering the surrounding shores. The native asphalt, as found, is naturally intimately mixed with organic salts and quantities of water. When refined it is used as a paving material (R. G. Smith).

Trunk pipe-lines.—Main lines of transportation joining two important points. Thus, many branch or "feeder" pipe-lines may convey oil to a central point in a producing district; from this point a trunk line conveys the oil to the refinery, or other terminal.

Tube clamp.—A clamp, or clip, for gripping a tube or pipe; especially a jawed tool used in hoisting and lowering well tubes (Standard).

Tube packing.—See Oil-well packing.

Tubing.—(1) The tube-lining of bore-holes; casing.
(2) The act of lining a deep bore-hole by driving down iron tubes (Ihlseng). See Casing.

Tubing catcher.—A device to prevent tubing from slipping back into an oil well when it is being pulled (National Tube Co.).

Tubular goods.—The term covering all classes of pipe, casing, and tubing used in drilling or operating oil or gas wells (Sands).

Turpentine substitutes.—Petroleum products usually intermediate between gasoline and illuminating oil (Bacon).

Twaddell.—A form of hydrometer for liquids heavier than water, graduated with an arbitrary scale such that when the readings are multiplied by 0.005, and added to unity, they give the specific gravity (Webster).

Twist-off.—(1) To break the drill pipe in the hole, usually by torsional stress.
(2) The result of such a break (Sands).

Unconformity.—A surface, separating two series of rocks, which indicates a pronounced time interval between the periods of formation of the two series, is called an unconformity. This time interval may also be accompanied by the deformation of one series previous to the formation of the other.

Underground water.—See Ground water.

Under-ream.—To enlarge a drill-hole below the casing.

Under-reamer.—An oil-well tool used for enlarging the hole below a drive shoe, etc. (National Tube Co.)

Union.—(1) The usual trade term for a device used to connect pipes.
(2) The act of joining or uniting two or more things. (3) The joint or connection thereby made (National Tube Co.).

Unsaturated.—(Said of hydrocarbons.) Having the property of taking on addition products, such as the halogen elements, without giving up hydrogen; such as the olefine and acetylene series, etc.

" Untest " stock.—Partially reduced steam-refined stock; a mixture of light ends and distillate from which the naphtha content is usually removed in a steam still; steam refined stock diluted with naphtha for filtering or cold settling (A. D. Smith).

Uplift.—Elevation of any extensive part of the earth's surface relatively to some other part; opposed to subsidence (La Forge).

Upset.—To increase the diameter of a rock drill by blunting the end. (Gillette.) Also applied to casing and tubing.

Upset end joint.—A reinforced joint in rotary drill pipe (Sands).

Upthrow.—The block or mass of rock on that side of a fault which has been displaced relatively upward (La Forge). The term should be used with the definite understanding that it refers merely to a relative and not an absolute displacement (Fay).

Upthrust.—An upheaval of rocks; said preferably of a violent upheaval; used also attributively (Standard).

Vacuum.—The degree of rarefaction of a partial vacuum, measured by the reduction of pressure from that of the atmosphere (Webster).

Valve.—Any contrivance, as a lid, cover, ball, or slide, that opens and closes a passage, whether by lifting and falling, sliding, swinging or rotating—as at the opening of, or inserted in, any pipe, tube, outlet, inlet, etc., to control the flow or supply of liquids, gases, or other shifting material (Standard).

Vapor.—Any substance in the gaseous state, under conditions where it is capable of being liquefied either by pressure or cooling alone. A gas below its critical temperature (D. T. Day).

Vapor density.—The relative weight of a gas or vapor as compared with some specific standard, usually hydrogen, but sometimes air (Webster).

Vaporimeter.—An instrument for measuring the volume or the tension of a vapor (Webster).

Vaseline; vaselin.—A trade name for a yellowish, translucent, semi-solid petroleum product, used in ointment and pomades, as a lubricant, and in other ways; a form of petrolatum (Webster).

Verifier.—(1) A tool used in deep boring for detaching and bringing to the surface portions of the wall of the bore-hole at any desired depth (Raymond). (2) In gas testing, an apparatus by which the amount of gas required to produce a flame of a given size is measured; a gas verifier (Standard).

Vernier.—Instrument named for its inventor, Pierre Vernier (1580–1637) used for measuring a fractional part of one of the divisions of the graduated fixed scale or arc. Used on a sextant. Also called nonius (Century).

Viscosity.—The property of liquids that causes them to resist instantaneous change of shape or of the arrangements of their parts; internal friction; gumminess (Rickard). The resistance which the particles of a liquid offer to a force tending to move them relatively (Gill). **Absolute viscosity:** that force which will move 1 square centimeter of a plane surface with a speed of 1 centimeter per second relative to another parallel plane surface from which it is separated by a film of the liquid 1 millimeter thick (Delbridge). **Critical viscosity:** the point at which friction changes from decreasing to increasing as the viscosity of the lubricant is increased—conditions of load, speed, and feed remaining constant (Gill). **Engineering unit of viscosity:** that viscosity which offers a resistance of 0.00291 pound to the relative motion at the rate of a foot per minute, of opposite faces of a film of the viscous liquid 1 square inch in area and 1/1000 of an inch thick (Gill).

Viscous.—Adhesive or sticky, and having a ropy or glutinous consistency (Webster). Characterized by viscosity.

Volatile.—Easily wasting away by evaporation; readily vaporizable (Webster); e.g., those fractions of bituminous materials which will evaporate at climatic temperatures.

Volumetric analysis.—The analysis of a compound by determining the quantity of a standard solution required to satisfy a reaction in a known quantity of the compound (Standard).

Volumetric horse-power.—The ratio between the weight of air contained in the cylinder of a four-cycle engine when the compression stroke begins and that of the air required to fill the same volume at atmospheric pressure (Goldingham).

Walking beam.—An oscillating beam or lever used to transmit reciprocating vertical motion to the drilling tools.

Walk out.—To follow up a prominent bench in order to plot structures by contours.

Wantage rod.—A gage rod for measuring the outage of a barrel, tank, or tank car.

Warp.—To deflect from a normal position.

Wash.—To pass a gas through or over a liquid for the purpose of purifying it (Webster). To cleanse or purify by agitation with a liquid which may contain cleansers, such as acid, alkali, or clay. See also Clay wash.

Washdown spear.—A fishing tool used in rotary drilling (Sands).

Washer.—An apparatus in which gases are washed; a scrubber (Webster).

Water-bound.—Confined with the aid of water (Bacon).

Water finder.—An instrument used for ascertaining the amount of water in a tank containing oil.

Water flush.—A system of well-boring, in which percussion drills are used in connection with water forced down to the bottom of the hole through the drill rods. This water jet makes the tools cut better, and washes the detritus up out of the hole (National Tube Co.).

Water gas.—A gas made by forcing steam over incandescent carbon (coke) whereby there results a mixture of hydrogen and carbon monoxide. It is sometimes used as a fuel, but usually is carbureted with illuminating constituents prepared from oil and used as illuminating gas (Webster). Steam passed through a mixture of hydrocarbons.

Water-gas tars.—Tars produced by cracking oil vapors in the manufacture of carbureted water gas (Bacon).

Water packer.—A device to cut off water from the lower levels of an oil well, or to separate two distinct flows of oil from different strata (National Tube Co.).

Water seal.—A seal formed by water to prevent the passage of gas (Webster).

Water-soluble oils.—Oils having the property of forming permanent emulsions or almost clear solutions with water (Bacon).

Water string.—A string of casing, often the last one set, used to shut off all water above an oil sand (Sands).

Water surface.—In oil wells, the level or inclined plane between the oil or gas, and the edge water upon which the oil or gas rests. Not to be confused with ground-water level or table (U. S. Geol. Survey).

Water swivel.—In rotary well-boring, a combined universal joint and hose coupling, forming the connection between the water-supply pipe and the drill rods, and permitting complete rotation of the tools (National Tube Co.).

Water white.—A grade of color in oil, defined as +25 in the scale of the Lovibond or Tagliabue colorimeter.

Watt.—An electrical unit of power or activity equal to work done at the rate of 1 joule a second or at the rate of work represented by a current of 1 ampere under a pressure of 1 volt. A volt-ampere. A horse-power is equal to 746 watts (Webster).

Wax.—An unctuous, fusible, and more or less viscous to solid substance, having a characteristic "waxy" luster, insoluble in water, but more or less soluble in carbon disulphide, benzol, etc. (Bacon).

Wax distillate.—Neutral oil distillates before the separation of paraffin wax (Bacon) An intermediate, the primary base for paraffin wax and neutral oils. It is an amorphous product, and for the most part requires rerunning before pressing (A. D. Smith).

Wax oil.—The immediate base from which paraffin wax and neutral oils are manufactured (A. D. Smith).

Wax tailings.—A residual product, containing chrysene, picene, and other compounds formed by destructive distillation of petroleum (Bacon).

Weathering.—(1) Exposure of wild (casing-head) gasoline to the air or heating it, as with steam, to allow the lighter vapors to escape into the air.

(2) Changes effected in rocks by atmospheric influences. Changes in color of rock surfaces due to the photographic action of light, as for example, the bleaching effect of light on oil-shales, cannot be considered weathering.

Well.—A shaft or hole sunk into the earth to obtain oil, gas, water, etc. (Webster).

Well rig.—An assemblage of all mechanisms, including power necessary to drilling, casing, and finishing a drilled well (Standard).

Well shooting.—The firing of a charge of nitroglycerin, or other high explosive, in the bottom of a well, for the purpose of increasing the flow of water, oil, or gas (Du Pont).

Well tube.—A tube or tubing used to line wells (Standard).

Well-tube filter.—A strainer on a driven well-tube to keep out grit (Standard).

Well-tube point.—A point at the end of a perforated tube used for sinking wells (Standard).

Westphal balance.—A form of balance used in determining the specific gravity of liquids, minerals, fragments, etc. (Webster).

" Wet " natural gas.—Natural gas containing readily condensable gasoline, which can be extracted in quantity sufficient to warrant the installation of a plant.

Whip stock.—A kind of fishing tool.

Widemouth socket.—A well-borer's fishing tool, in which the socket is fitted with a bell-mouth, nearly the full bore of the casing, thus making it easy to grip the ends of broken poles or the like, when lost at the bottom of a well (National Tube Co.).

Wildcat.—This term is now specifically applied to an oil company organized to develop unproven ground far from the actual point of discovery.

Wildcatter.—One who drills wells in the hope of finding oil in territory not known to be an oil-field (Webster).

Wildcatting.—Drilling wells for oil in territory not yet proven to be oil-bearing. Prospecting for oil with the drill.

Wild gasoline.—Casing-head gasoline.

Wild well.—An oil well, the flow of which has not been brought under control.

Wire rope.—A rope whose strands are made of wires, twisted or woven together (C. M. P.).

Wool stocks.—Sun-bleached neutral oil, compounded with lard oil to make a rich, creamy emulsion (Bacon).

Working barrel.—The body of a pump used in oil wells (National Tube Co.).

Worm.—A coil of pipe for condensing vapors.

Wurtzilite.—See under Elaterite.

Yellow wax.—A viscous, semi-solid, substance of high boiling point obtained on the distillation of petroleum still residuum.

Yield.—The proportion of oil or gas, etc., obtained in mining; extraction; recovery.

Zone of capillarity.—An area that overlies the zone of saturation and contains capillary voids, some or all of which are filled with water that is held above the zone of saturation by molecular attraction acting against gravity (Meinzer).

Zone of saturation.—An area which contains capillary or supercapillary voids, or both, that are full of water that will move under ordinary hydrostatic pressure (Webster).

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